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Experimental Translocation of the Florida Sand Skink (*Plestiodon* [=Neoseps] *reynoldsi*): Success of a Restricted Species Across Diverse Microhabitats

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Experimental Translocation of the Florida Sand Skink (*Plestiodon* [=Neoseps] *reynoldsi*):

Success of a Restricted Species Across Diverse Microhabitats

by

Nicholas Paul Osman

A thesis submitted in partial fulfillment
of the requirements for the degree of
Master of Science
Department of Biology
College of Arts and Sciences
University of South Florida

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Dedication

This thesis is dedicated to my parents, Lloyd and Cam Osman, and my partner, Marc Kurtzman, for all of their love and support.

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Experimental Translocation of the Florida Sand Skink (*Plestiodon* [=Neoseps] *reynoldsi*):
success of a restricted species across diverse microhabitats

Nicholas Paul Osman

Abstract

The fossorial Florida Sand Skink (*Plestiodon* [=Neoseps] *reynoldsi*) inhabits a restricted range of scrub and sandhill fragments on the ridges of central Florida. The high rate of urban and agricultural development in this area necessitates conservation strategies other than land acquisition and management because of the limited remaining Florida Sand Skink habitat available. This study tests the viability of translocation as a conservation strategy for this species and assesses which features of a recipient site contribute to the successful establishment of a population. In 2007, 300 individuals were collected and moved from an intact scrub habitat, individually marked, and moved to a nearby reclaimed site with no existing Florida Sand Skink population. Fifteen 20 m² enclosures were constructed at the recipient site, and 20 skinks were randomly assigned to each. These enclosures were divided among five treatments, which represented the range of habitat types at the donor site and differed in the presence or absence of a shade-providing object and coarse woody debris. Translocated skinks were monitored for two years to measure survival and reproduction. While survival and reproduction were apparent in all treatments, survival was significantly greater in enclosures with no shade-providing object and low soil moisture, and reproduction was most evident in enclosures with less light intensity and soil compaction. Common measurement of environmental variables at the donor and recipient sites showed that all of the recipient site enclosures differed from the donor site in the amount of vegetative cover but contained the structural heterogeneity that is associated with Florida Sand Skink presence in the wild. This study indicates that translocation is a practical conservation strategy for this species, and my results can be used to inform protocol for future Florida Sand Skink translocation efforts.

Introduction

The Florida Sand Skink (*Plestiodon* [=Neoseps] *reynoldsi* Stejneger) is precinctive to scrub and sandhill habitats on the ridges of central Florida, remnants of the once widespread xeric conditions of the late Pliocene era prior to Pleistocene sea level rise (Watts and Hansen 1988, Branch *et al.* 2003). The Lake Wales Ridge (LWR), by far the largest of these ancient sand dunes, has had 85% of its original 2400 km² developed for agricultural, commercial, and residential use (Turner *et al.* 2006). Consequently, the Florida Sand Skink is federally listed as a “threatened” species (U.S. Fish and Wildlife Service 1987). A recent assessment of the effectiveness of protecting remaining undeveloped land to reduce the risk of extinction of LWR species found that the acquisition of additional reserves would have little impact on the success of the Florida Sand Skink (Turner *et al.* 2006), emphasizing the importance of effective management practices in existing reserves. While land acquisition and management are important, the continued high rate of development on the LWR and other ridges necessitates alternative conservation strategies. One such strategy being considered is the restoration of vegetation on reclaimed developed lands and subsequent translocation of Florida Sand Skinks from sites commissioned for development to these areas.

Translocations are broadly defined as the movement of living organisms by humans from one area to another within their range (IUCN 1987, Reinert 1991, IUCN 1998), and the suitability of reptiles as candidates for this action and its effectiveness as a conservation strategy have been debated based on reviews of previous efforts (Griffith *et al.* 1989, Burke 1991, Dodd and Seigel 1991, Germano and Bishop 2008). As a result, several recommendations are available to those considering translocation. These reviews emphasize (1) the need to understand the species and the threats that face it at its existing location (henceforth referred to as the “donor site”); (2) the importance of the quality of the site to which the species is being translocated (henceforth referred to as the “recipient site”); and (3) the obligation to set clear goals and follow

through with long-term monitoring. More recent reviews also stress the need for experimental approaches to translocations in order to develop standardized techniques before the practice is adopted as a conservation strategy for a species (Seddon *et al.* 2007).

In their review of reptile translocations, Germano and Bishop (2008) found that success was independent of the number of animals translocated or the age at which they were moved, and failure was most often associated with dispersal away from the recipient site. The second most common reason for failure was the low quality of habitat at the recipient sites. Griffith *et al.* (1989) found a similar trend in their review of bird and mammal translocations, as did Rout *et al.* (2007) when using a modeling approach: success was most often related to the quality of the recipient site rather than the quantity of animals released.

The importance of recipient site quality poses a challenge to translocation efforts involving the Florida Sand Skink because of the lack of a firm understanding of its habitat preferences in the wild. Studies of the Florida Sand Skink's habitat associations often have ambiguous or contradictory results. In fact, a study by McCoy *et al.* (1999) showed that literature descriptions of suitable habitats are often poor predictors of actual Florida Sand Skink abundance. Furthermore, Florida Sand Skink populations continue to be discovered in habitats that are otherwise characterized as unsuitable and are often absent from other seemingly suitable sites (Sutton 1996, Pike *et al.* 2007).

Within scrub and sandhill habitats on the LWR, Florida Sand Skink density is most often correlated with the presence of bare, loose sands that are low in moisture (Sutton 1996, Navratil 1999, Gianopulos 2001). These soil conditions allow them to freely "swim" through the sand, a form of locomotion to which they are morphologically adapted. Like other fossorial species, the Florida Sand Skink has a relatively short tail and elongated trunk, its limbs are significantly reduced in size and number of digits, and it has a countersunk lower jaw and wedge-shaped snout (Telford 1959). The dry, bare, loose sands that are conducive to "sand-swimming" are often the result of the lack of dense vegetative cover, and therefore Florida Sand Skink presence is often associated with sparse canopy cover (McCoy and Mushinsky 1991, Sutton 1996) and understory vegetation (Gianopulos 2001). However, the habitat characteristics that contribute to

their ease of movement through the sand are in conflict with habitat characteristics that meet their thermoregulatory and nutritional needs. For instance, Collazos (1998) found Florida Sand Skink presence to be strongly associated with areas of relatively low soil temperatures resulting from shade from trees, shrubs, and grasses. Another study found that capture locations were positively associated with grass and shrub cover when there was no canopy present but negatively associated with grass and shrub cover when a canopy was present (Hill 1999), highlighting the importance of shade-providing objects for thermoregulation. The importance of thermoregulation for the Florida Sand Skink is evidenced by the fact that their periods of movement in the wild are strongly tied to their preferred temperatures. Florida Sand Skink's time of daily activity changes seasonally to meet the time of day when surface sand temperatures are between 28 and 32°C, and they are most active during their spring mating season, when these temperatures occur most frequently (Andrews 1994). Vegetation also serves two other critical functions through its associated debris and root structure: (1) it holds moisture, which must be at least minimally available to the Florida Sand Skink for hydration (Telford 1965) and (2) it attracts the Florida Sand Skink's prey, which is primarily beetle larvae and termites (Myers and Telford 1965, Smith 1977, McCoy *et al.* in review).

The apparent contradiction in habitat features necessary for the Florida Sand Skink's ability to move and their ability to thermoregulate, hydrate, and find prey has led to several conclusions in the literature about optimal Florida Sand Skink habitat. Hill (1999) proposed that structural heterogeneity is key, such as areas with differing strata of vegetation adjacent to bare, open areas (Hill 1999). McCoy *et al.* (1999) questioned the notion that there is "optimal" Florida Sand Skink habitat at all. Similarly, Gianopulos (2001) concluded that their presence is likely tied to specific microhabitat features, which can be present in several different scrub and sandhill habitat types. These conclusions make the design of a recipient site for translocation of the Florida Sand Skink difficult.

Indeed, poor recipient site quality has had a negative impact on the outcome of previous translocation efforts involving the Florida Sand Skink and other fossorial lizards. Monitoring two years after the relocation of a population of slow-worms (*Anguis fragilis*), a European legless

semi-fossorial lizard, showed that population size, reproduction, and body condition had decreased, in part due to the poor quality habitat at the recipient site (Platenberg and Griffiths 1999). The model for this translocation was similar to that proposed for future Florida Sand Skink translocations, where individuals were moved from a site scheduled for development to a recipient site that was previously developed, reclaimed, and altered to increase the likelihood of survival. An initial experimental translocation of the Florida Sand Skink has been conducted and also followed this model (Hill 1999, Penney 2001). This study involved two reclaimed recipient sites, an abandoned citrus grove and an abandoned pasture. Each site was cleared of most of its vegetation and topsoil and divided up among four treatments, which differed in the way that topsoil and vegetation taken from the donor site were treated before being relocated to the recipient site (mulching, burning, lack of treatment, etc.). The 154 Florida Sand Skinks that were captured at the donor site were divided among the recipient sites and treatments within each site. Six years after the translocation, difference in capture rates among treatments was negligible and only one of the sites supported a self-sustaining population. This site, however, was contiguous with a well-established scrub habitat that likely helped to support the translocated (as well as a native) Florida Sand Skink population. The alteration of the reclaimed recipient site in this study emphasized the vegetative species make-up rather than the structural role and ecological functions of the vegetation.

The present study tests the viability of translocation as a conservation strategy for the Florida Sand Skink and assesses which features of a recipient site contribute to successful establishment of a translocated population. An experimental approach is used, manipulating structural elements such as canopy, root structure, and debris within enclosed recipient sites, rather than attempting to recreate vegetative species composition. Releasing individuals into enclosed areas ensures that success or failure will be attributed to the treatments given to these areas, as well as increases the probability of recapturing survivors. Moreover, by correlating structural habitat elements with Florida Sand Skink density at the donor site, a better understanding of habitat associations in the wild can be obtained. Measurement of common

environmental variables at both sites will allow comparisons to determine the quality of habitat at the recipient site.

Previous studies of Florida Sand Skink habitat associations in the wild indicate that survival will be possible over a range of microhabitat types and that structural heterogeneity may be an important factor for success. The results will inform protocol for future translocation efforts involving the Florida Sand Skink.

Methods

Donor Site

Two hundred and ten trap arrays were constructed at the donor site near Davenport, Florida, an approximately 1.2 km² scrub habitat in Polk County on the north-central part of the Lake Wales Ridge (Lat. 28.17920, Long. -81.56499) (Fig. 1). This site was scheduled to be used as a sand mine, but at the time of trapping it supported a relatively dense Florida Sand Skink population (approximately 600/ha) and was dominated by sand live oak (*Quercus geminata*) and scrub palmetto (*Sabal etonia*) with large open spaces between areas of vegetation. The 210 trap arrays were divided among four sites of 50 arrays each and two sites of five arrays each (Fig. 2). The smaller two sites were constructed for a concurrent genetic study, but Florida Sand Skinks captured in them were used for the analyses and translocation nonetheless. Each trap array consisted of four 2 m aluminum flashing drift fences pointing in each cardinal direction, and each drift fence had two 3.8 L buckets on each side, totaling 16 buckets per trap array (Fig. 3). Arrays were approximately 8 m² in size and were spaced about 20 m apart within sites. The buckets were countersunk in the ground so that the rim was 5 to 10 cm below the surface of the sand. The lids that provided shade were held up using sticks, creating at least an inch of room for skinks to enter. Small holes were created at the bottom of the buckets for drainage and water was added to the inch of sand in the bottom of the buckets during periods of no rain. At four of the sites, a 20 m² enclosure was built for the concurrent genetic study. These enclosures were the same as those at the recipient site described below. Florida Sand Skinks captured within these enclosures were used for the translocation, but neither the number of individuals captured inside these enclosures nor any environmental data from them was included in any of the analyses described below.

Traps were opened from March 28 to May 25, 2007 and checked every other day by a team of field technicians (Entrix Inc., Riverview, FL). The number of Florida Sand Skinks captured

at each array was recorded. To assess whether individuals were captured at fewer arrays than would be expected by chance given the total number of arrays and the total number of individuals captured, a Monte Carlo simulation was performed with 1000 iterations using Resampling Stats v5.02 (Simon 2000). This procedure created 95% confidence intervals around the expected proportion of arrays at which individuals would be captured by chance. If skinks were captured at fewer arrays than expected, an investigation into the habitat features associated with areas of high trap frequency would be warranted.

At each trap array, a 1 m² quadrat was laid between each pair of adjacent drift fences (four quadrats per array, Fig. 3), and the percent of the quadrat filled by (1) bare ground, (2) live vegetation, (3) lichen, and (4) leaf litter and debris (total =100%) was estimated. The percent filled by coarse woody debris that may have enhanced prey species abundance was also estimated, but this percentage did not count toward the 100% filled by the other groundcover features. Light intensity (in Lux) was measured with a light meter (Extech Instruments Corporation, Waltham, MA) laid on the ground in the center of the quadrat, and it was later corrected if the reading was taken while the sun was behind a cloud. Measurements taken while the sun was behind a cloud (a situation that was minimized) were separated from those taken in full sun. Each measurement was then converted to a percentage of the maximum light intensity measured in its category (full sun or cloudy). Canopy height was recorded using categorical measures: 1 = less than 1 m, 2 = 2-3 m tall, and 3 = greater than 3 m tall. A penetrometer was used to measure the soil compaction. The pressure (in pounds per square inch) needed to reach the first abrupt change in compaction ("break") was recorded, as well as the depth at which this break occurred. The data from the four quadrats at each array were averaged. When these averages were used for statistical analyses, raw percentage data were arcsine-square-root transformed before averaging. Moreover, a soil corer was used to sample the soil at the center of each array for soil moisture analysis. These samples were weighed before and after drying at 100°C for 24 hours in a drying oven, and the percentage of moisture was calculated.

Because of the likelihood of intercorrelation of these data, principal component analysis was used to reduce the number of variables. The scores from the components that explained

most of the variation in the data were tested for correlation with the total number of Florida Sand Skinks captured at each array. Soil moisture was tested for correlation with the number of captures per array separately in order to maintain consistency with the analyses below. Soil moisture was also tested for significant correlation with the principal component scores using Spearman's Rank Test of Correlation. All statistical analyses were carried out using the program Statistica version 9 (StatSoft, Inc.), unless otherwise noted.

Recipient Site

The mass, sex, and snout-vent-length (SVL) of each Florida Sand Skink captured at the Davenport, FL site during 2007 was recorded, and each individual was given an individual mark using a distinct spatial and color combination of a biocompatible fluorescent plastic polymer injected under the skin (Northwest Marine Technology, Inc., Shaw Island, WA) (see Penney *et al.* 2001 for comments about using this technique with Florida Sand Skinks). Each individual was given three marks, which consisted of one to four colors and spanned six possible locations on its ventral side (Fig. 4). The first 300 Florida Sand Skinks captured at the donor site in 2007 were released into fifteen 20 m² experimental enclosures at the recipient site within the Reedy Creek Improvement District. This site, located approximately 24 km north of the donor site (Lat. 28.41379, Long. -81.61898), is a 6.07 ha isolated upland within the Reedy Creek Swamp. It consists of Candler and Tavares fine sands and was formerly used as a citrus grove but now supports a dense population of the Gopher Tortoise (*Gopherus polyphemus*) and scattered mature sand live oaks (*Q. geminata*). No Florida Sand Skinks inhabited this site prior to the translocation. Of the first 300 individuals captured at the donor site, 20 were released in each of the 15 enclosures, which consisted of three replicates of five treatments. The remaining Florida Sand Skinks captured at the donor site also were brought to the recipient site but were released outside of the experimental enclosures for future study. These individuals' marks indicated that they were not initially released into an enclosure so that they would not accidentally be included in this study if they subsequently moved into enclosures.

The five treatments resembled different microhabitat types and represented the variation of microhabitat types at the donor site. They differed in the presence or absence of (1) a shade-providing object, which was either one of the mature trees that already existed at the recipient site or a shade-cloth suspended two meters above the ground on a wooden frame, and (2) added coarse woody debris, which is thought to provide refuge and attract prey insect species. The treatments, which are shown in Figure 5, are as follows: (1) shade from a tree and woody debris (referred to as “Tree+Wood” for analyses), (2) shade from a tree but no woody debris (“Tree”), (3) woody debris but no shade (“Wood”), (4) shade from a shade-cloth (to assess the effects of trees such as soil compaction or leaf litter) and no debris (“Shadecloth”), and (5) no shade or debris (“Control”). The spatial arrangement of the treatment enclosures was similar to that of a randomized block design, in which there were three groups of enclosures (“blocks”), each containing one replicate from each of the five treatments (Fig. 6). Each enclosure contained sixteen 2 m aluminum flashing drift fences with two countersunk 3.8 L buckets at the end of each. Twelve buckets were also arranged along the inside of the aluminum flashing enclosure walls, for a total of 76 bucket-traps per enclosure (Fig. 7) (Sutton 1996). Each drift fence was given a number (1 through 16) and each wall of the enclosures was referred to as the north, east, south, or west wall.

In recognition of the uncertainty in the number of Florida Sand Skinks that would be captured at the donor site, the assignment of individuals to treatments was done in such a way that would assure equal numbers of individuals within each enclosure even if 300 were not captured. Individuals caught at the donor site were assigned to enclosures in groups of five, rotating through the enclosures mixed among treatments until each had 20 individuals. This density approximates normal Florida Sand Skink densities in good habitat (600/ha) (Sutton 1996, Collazos 1998, Mushinsky and McCoy 1999), but this method did not allow each enclosure to contain equal proportions of males, females, and juveniles.

Traps were opened the following two years during the time of Florida Sand Skink peak activity to assess survival and reproduction. Traps were opened from March 4 to May 28, 2008 and from March 3 to May 27, 2009. As with the donor site, opening and checking traps included

elevating the bucket lids with sticks, adding water when needed, maintaining one to two inches of sand at the bottom of each bucket, and creating small holes for drainage. During the trapping period, each bucket-trap was checked every other day, even if all bucket-traps were not checked in the same day. Traps were always checked by “block” (i.e. one replicate set) so that each treatment always received equal “trap effort” on any given day. When a Florida Sand Skink was found, its mark, sex, and the location at which it was found were recorded. In 2009, snout-vent length was recorded as well. Coded into each Florida Sand Skink’s individual marking was the treatment to which they were initially assigned. If a skink was captured in a treatment enclosure different than the one to which it was initially assigned, it was put back into its original treatment enclosure and was not included in that year’s recapture data. If an individual was missing one of the marks, its identity could usually be deduced based on its remaining marks, sex, and location. If a recaptured individual’s identity could not be deciphered, it was not included in any analyses. If an individual had no marks, indicating that it was born at the recipient site, it was brought back to the laboratory. Its sex, mass, and SVL were recorded, and it was given a new individual mark that corresponded to the treatment enclosure in which it was found, where it was subsequently released.

During the 2009 trapping season, the same environmental data collected at the donor site were collected at the recipient site. Within each enclosure, a 1 m² quadrat was used to measure groundcover, light intensity, soil compaction, and canopy height, in 16 locations (Fig. 7) using the methods described above. Soil samples were taken at three random locations within each enclosure to determine soil moisture using the methods described above. Furthermore, two ThermoChron iButton temperature loggers in each enclosure recorded the temperature every half hour during a two-week period of maximum capture frequency at the recipient site in 2009. This time period was determined based on the 2008 capture frequencies. One temperature logger was placed in the center of each enclosure and the other was placed at a randomly determined distance (maximum 10 m) and direction from the center. At these locations, the temperature loggers were buried under a few centimeters of sand, within grass, or under debris, attempting to replicate the space occupied by the Florida Sand Skink. The temperature frequencies were

determined within each enclosure and the percentage of recordings that were within the Florida Sand Skink's preferred temperature, 28°C and 32°C (Andrews 1994), was determined.

Differences in these environmental variables among treatments were tested using one-way ANOVA. Each variable was tested individually and Tukey's HSD tests were used for post hoc analysis. Differences among treatment replicates were also tested using one-way ANOVAs. Then, the enclosure average for each variable was used in a hierarchical clustering analysis to see if replicates of the same treatment would be grouped together based on the environmental variables measured. Euclidean distances were used to assess similarity between enclosures for clustering.

To compare the recipient site to the donor site, measures from within the enclosures at the recipient site were used as "supplementary cases" in the principal component analysis described above. This procedure would assign each point of measurement at the recipient site component scores based on the loadings from the PCA of the donor site data. For the components that explained most of the variation in data at the donor site, the scores from the donor site array and recipient site enclosures would be compared using Mann-Whitney U tests. Because only three soil samples were taken at each site, soil moisture was independently compared between sites also using a Mann-Whitney U test.

Survival

Treatment and Block Effect

The total number of unique recaptures over the two years was calculated for each enclosure and two one-way ANOVAs were run, with treatment and block as the factors. This procedure was done for each year individually as well. Recapture data were analyzed also using the program MARK (White and Burnham 1999), which estimates survival rate (ϕ) and recapture probability (P). The models used to calculate these estimates account for deaths caused by trapping as well as "missed" recaptures. In the case of trapping deaths, a Florida Sand Skink that was found dead in 2008 would not affect ϕ or P when it is not found in 2009. "Missed" captures were cases in which a Florida Sand Skink released in 2007 was not recaptured in 2008 but was

recaptured in 2009, and ϕ and P would be affected accordingly. A standard Cormack-Jolly-Seber capture-recapture model was chosen for MARK analyses.

The method of ϕ and P estimation in MARK is constrained by the grouping of recapture events and released individuals set by the user. For instance, one estimate of survival can be obtained for the entire duration of the study (constant ϕ) or, alternatively, survival rate can be estimated for the interval between each recapture event (time-dependent ϕ). Similarly, survival rate can be estimated for each of the five treatments or one estimate of survival can be generated for the entire translocated population. My goal was to find which model best explained the variation in the recapture data among a set of models in which survival was estimated for the enclosures grouped in different ways. A treatment effect could be inferred if a model that estimates survival for each of the five treatments was found to be more parsimonious than either of the following models: (1) one that generates only one survival estimate for all enclosures or (2) one that generates a survival estimate for each of the three “blocks”. Before the effect of enclosure grouping on model parsimony could be assessed directly for ϕ , the effect of enclosure grouping and time on P had to be determined. In other words, any treatment, block, or time effect on recapture probability had to be determined before I could assess whether there was a treatment or block effect on survival. I did not use models in which ϕ estimation was time-dependent because in MARK only the product of ϕ and P for the last interval is identifiable, and therefore time-dependence could not be incorporated into both ϕ and P (Lebreton *et al.* 1992). Nevertheless, the focus of this analysis was to determine if there was an effect of treatment on survival and not to assess difference in survival between years.

Eleven candidate models were run to determine whether there was a group or time effect on P . I chose a “null” grouping of enclosures for ϕ estimation for these models, in which only one estimate was generated for all enclosures (ϕ). The 11 different group and time combinations used for P estimation included grouping enclosures by block (P_B , three estimates) and by treatment (P_R , five estimates), as well as grouping all enclosures together (P_{\cdot} , one estimate) and not grouping them at all (P_E , 15 estimates). For each of these, time-dependence was then included ($P_{B \times T}$, $P_{R \times T}$, P_T , and $P_{E \times T}$, respectively). $P_{B \times T}$, $P_{R \times T}$, and $P_{E \times T}$ models were each run with

and without the group-time interaction ($P_{B \times T \times B \times T}$ etc.). If a model with the interaction included is more parsimonious than one without the interaction included, it is similar to having a significant interaction effect in an analysis of variance.

Once the best model for P estimation was chosen, it was used to find the most parsimonious grouping of the enclosures for Φ estimation. Models Φ_{\cdot} , Φ_E , Φ_B , and Φ_R were compared, as well as a model that accounted for the treatment and block effect ($\Phi_{R \times B}$). Like Φ_E , this model returned 15 estimates, but each enclosure was assigned to a treatment and block. This model was also run with the treatment-block interaction included ($\Phi_{R \times B \times R \times B}$).

I fit another group of models to the data to assess the individual effects of shade, the presence of trees, and the presence of coarse woody debris. This analysis would determine the effects of the three treatments given to enclosures, regardless of which other treatment an enclosure was also given. For each of three models ran in MARK, Φ was estimated for two groups of enclosures: (1) the enclosures given coarse woody debris and those that were not (Φ_{wood}); (2) those that had a tree in them and those that did not (Φ_{tree}); and (3) those that had a shade giving object (whether a tree or shade-cloth) and those that did not (Φ_{shade}). These models were compared to the null model (Φ_{\cdot}) and a model that grouped enclosures into the five treatments (as described above, Φ_R). All of these models were run using both time-dependent and constant recapture probability estimation (P_T and P_{\cdot} , respectively). A two-way ANOVA was also used to compare the total unique captures in each enclosure between these groups (trees and no trees; shade and no shade; and wood and no wood). The ANOVAs were also run for each trapping year individually. "Block" was the other factor in these analyses. A two-way ANOVA was possible in this case because there was replication within groups, unlike the ANOVA for the comparison of treatments above.

Effect of Environment

The following analysis ignores the grouping of enclosures into treatments or blocks and focuses on the relationship between recaptures and environmental data within each individual enclosure. The relationship between survival and habitat in each enclosure was first assessed

using Spearman's Rank Correlation Test. The total number of unique recaptures within each enclosure was tested against the enclosure average for each of the environmental variables measured (described above).

In MARK, parameter estimates (ϕ and P) can be constrained to be linear functions of a covariate. I used the enclosure average for each environmental variable measured as covariates for this type of analysis. One covariate per model was used for ϕ estimation, while P estimation was time-dependent (P_T , based on the above analyses). These 10 models were compared to a model which also estimated ϕ for each enclosure but was not constrained by a covariate (ϕ_E), as well as the "null" model which estimated only one ϕ (ϕ).

Effect of Sex, Age Class, and Size

The recapture rates of males, females, and juveniles (at the time of release) were calculated from the recapture data combined for both trapping years and all enclosures. Subsequently, MARK was used to estimate ϕ for males, females, and juveniles. A model that incorporated sex and age class into survival rate estimation ($\phi_{MFJ}P$) was compared to a model that did not account for sex and age class ($\phi.P$). These models were also run with time-dependence incorporated into recapture probability estimation ($\phi_{MFJ}P_T$ and $\phi.P_T$) for comparison.

A Mann-Whitney U test was used to compare the SVL and mass (at time of release) of recaptured and non-recaptured Florida Sand Skinks. Furthermore, MARK allows these individual covariates to be incorporated into the model structure. I ran models that included the mass and SVL of each Florida Sand Skink that was released into enclosures ($\phi_{\text{mass}}P$ and $\phi_{\text{SVL}}P$). I then included the square of mass and SVL into these models ($\phi_{\text{mass}^2}P$ and $\phi_{\text{SVL}^2}P$). If these latter models were more parsimonious than the former, it may indicate that intermediate-sized individuals were surviving better than individuals at the extremes of size. All of these models were also compared to a null model that did not account for size heterogeneity ($\phi.P$). This set of models was re-run with time-dependence incorporated into P estimation (P_T).

Finally, the SVL and mass of males, females, and juveniles were compared using a Kruskal-Wallis analysis of ranks test to assess the independence of any sex, age, and size effect found. Mann-Whitney U tests were used for post-hoc comparisons.

Effect of Trap Location

The effect of trap location at the donor site on survival was then similarly determined. The recapture rate was calculated for Florida Sand Skinks captured at each of the six trap sites within the donor site, followed by a model comparison using MARK. A model that incorporated the initial capture sites of the Florida Sand Skinks into survival rate estimation ($\phi_{\text{trap site}}P.$) was compared to a null model ($\phi.P.$). These models were then re-run with time-dependent recapture probability ($\phi_{\text{trap site}}P_T$ and $\phi.P_T$).

Model Comparison and Assessing Model Fit

For each of the above analyses using the program MARK, the most parsimonious model was chosen from a set of candidate models based on corrected Akaike's information criterion (AICc). Parsimony, in this case, is based both on the fit of the model to the data (model deviance) and the number of parameters estimated in the model. The AICc values take into account both of these features and will decrease with increasing parsimony. Likelihood ratio tests (LRT), available as part of the program MARK, were used to test for significant differences between models. The LRT procedure, which produces a p -value based on a Chi-squared test, can only be used to compare two models that are nested (i.e. when one model is a reduced version of the other). Therefore, AICc values (Cooch and White 2001) were also used when comparing models. While there is no p -value when comparing AICc values, Anderson and Burnham (1999) recommend that the difference in AICc values exceed 2 for any pair of models to be considered significantly different.

Before these comparisons could be made, the most parameterized model in each analysis was assessed for its goodness-of-fit to the recapture data. I used the standard GOF bootstrap test available in MARK. This test generates a model deviance for simulations that can

be compared to the observed deviance. The probability of obtaining a deviance as large as the observed deviance was calculated based on 100 simulations. Because the simulated data perfectly fit the model assumptions, this probability could be used to assess whether the model being tested was adequately fit to the data. Lack of fit can be interpreted as either a violation of the assumptions of the underlying CJS model or under- or over-dispersion of the data. Lack of fit can be accounted for in the model by adjusting the “variance inflation factor”, or $c\text{-hat}$. The adjusted $c\text{-hat}$ is found by dividing the observed deviance by the average of the simulated deviances. Lebreton *et al.* (1992) suggest that this is acceptable if the adjusted $c\text{-hat}$ is below 3 because the lack of fit may be caused by over-dispersion. If the lack of fit is greater, the results of the analysis are considered unreliable. If $c\text{-hat}$ is adjusted, AICc and model deviance are referred to as QAICc and QDeviance, respectively.

Reproduction

The total number of Florida Sand Skinks found without marks within each enclosure was compared with two one-way ANOVAs, with treatment and block as the factors. This procedure was done for each year individually as well. Two-way ANOVAs were also run that compared the number of individuals born in each enclosure between the following enclosure types: enclosures with trees and those without trees; enclosures with shade in the form of trees or shade-cloth and those without shade; and those with coarse woody debris added to them and those without woody debris added (as described above). Block was the second factor in each of these tests. Finally, Spearman's Rank Correlation Tests were used to detect any relationship between the number of individuals born in each enclosure and the enclosure average for each environmental variable measured.

Results

Donor Site

Five hundred and ten Florida Sand Skinks were captured at the donor site near Davenport, FL. These captures took place at 171 of the 210 trap arrays, or 81.4% of arrays. Based on the number of individuals captured, the Monte Carlo simulations generated a 95% confidence interval ranging from 87.6% to 94.3%. Therefore, individuals were caught in significantly fewer traps than would be expected by chance, indicating aggregation. Trap frequency ranged from 0 to 60 individuals captured per day and was greatest from late April to early May (Fig. 8). The number of skinks captured per array ranged from 0 to 9 (Fig. 9).

The first three components from the PCA explained 69.25% of variation in the donor site environmental data: 42.74, 14.28, and 12.23% respectively. The respective eigenvalues for these components were 3.9, 1.3, and 1.1. The other six components each accounted for less than 10% of the variation. Figure 10 shows the contribution of each variable to the first two components (loadings). A significant positive correlation exists between the number of Florida Sand Skinks caught at each array and the scores from the first principal component for each array (Wald $X^2=20.86$, $df=1$, $p<0.01$) (Fig. 11). Based on the loadings, low scores on this first component (PC1) corresponded to high canopy cover and high amounts of groundcover made up of dead vegetation and coarse woody debris. Higher PC1 scores were associated with a large amount of bare ground and high light exposure. Greater soil compaction, in the form of higher pressure measurements with the penetrometer, was also associated with greater PC1 scores. Neither the PC2 scores (Wald $X^2=2.13$, $df=1$, $p=0.14$) nor the PC3 scores (Wald $X^2=1.13$, $df=1$, $p=0.29$) were significantly correlated with the number of captures at each array. Greater PC2 scores were associated with more live vegetation and lichen as groundcover, as well as a greater depth at which the penetrometer hit an area of high compaction, indicating looser soils. Bare ground was associated with a low PC2 score in addition to its high PC1 score. PC3 loadings were greatest for

penetrometer pressure and depth, both of which were negative. In theory, pressure and depth should be inversely related, and thus, PC3 was not considered an important indicator of the variation in environmental data. Moreover, there was a significant positive correlation between the percent soil moisture and the number of individuals captured at each array at the $p = 0.1$ level. (Wald $X^2=3.05$, $df=1$, $p=0.08$) (Fig. 12), and the percent of soil moisture was positively correlated with PC1 scores at each array (Spearman's $\rho=0.19$, $p<0.05$) but not PC2 scores (Spearman's $\rho=0.10$, $p>0.05$). A Poisson regression model was used for the above analyses involving the number of individuals captured at each array because of the "Poisson-like" distribution of those captures (Fig. 9). However, because the distribution of captures was significantly different than a Poisson distribution ($X^2=45.04$, $df=8$, $p<0.00$), a feature in the program Statistica that accounts for "over-dispersion" was used for better model fit.

Recipient Site

Significant differences exist between treatments for all of the variables measured except the temperature measurement. Table 1 displays these differences. Significant differences in the environmental variables among replicates are displayed in Table 2 (with statistical values). The clustering analysis grouped at least two replicates from each treatment together. One replicate from each of the treatments "Tree", "Tree+Wood", and "Shadecloth" was separated from the other two replicates and grouped with the "Control" enclosures, forming the major two groups that resulted from this analysis. The "Wood" replicates were grouped together and equally close to both of the major groupings (Fig. 13).

Most of the "supplementary" component scores from the recipient site were outside of the range of the scores from the donor site (Fig. 14). The recipient site had significantly lower PC1 scores ($U=20791.0$, $df=1$, $p<0.01$) and significantly higher PC2 scores ($U=9446.0$, $df=1$, $p<0.01$). However, all of the enclosures without trees were within the range of scores at the donor site for the first principal component, which corresponded to the amount of canopy, detritus, bare ground, and light. All of the enclosures with trees were within the range of the donor site PC2 scores, which corresponded to the amount of bare ground, live vegetation, and soil compaction.

Furthermore, the percent soil moisture was not significantly different between the donor and recipient sites ($U=4179.0$, $df=1$, $p=0.22$).

Survival

Because more than 300 Florida Sand Skinks were captured at the donor site, each experimental enclosure at the recipient site had the maximum number of 20 individuals released into it. The number of males, females, and juveniles released into each enclosure, as well as how the individuals captured at each area of the donor site were divided among enclosures, is shown in Table 3. Of the 300 Florida Sand Skinks released into the enclosures, 105 had been recaptured after two years of trapping efforts during their active season, corresponding to a 35% recapture rate. The null models used throughout the analyses in the program MARK estimated the overall survival rate to be 49.1% (with a 95% CI of 35.2-63.2) when time-dependence was not incorporated into recapture probability estimation ($\Phi.P.$) or 69.3% (with a 95% CI of 49.2-84.0) when it was ($\Phi.P_T$). There were 69 unique recaptures in 2008 and 62 unique recaptures in 2009, with 26 of those occurring in both years. This corresponds to annual recapture rates of 23.0% in 2008 and 20.7% in 2009.

Capture frequency, or the number of individuals captured per trapping event, ranged from 0 to 13 individuals per “block” (set of five enclosures, one from each treatment), and the times of peak capture frequency in both 2008 and 2009 (Fig. 15) were similar to peak capture frequency at the donor site (Fig. 8).

Treatment and Block Effect

I found no significant treatment ($F=1.57$, $df=4$, $p=0.27$) or block ($F=0.89$, $df=2$, $p=0.45$) effect on the number of unique recaptures within each enclosure totaled for both years (Figs. 16 and 17). No effect of treatment ($F=1.49$, $df=4$, $p=0.29$) or block ($F=0.10$, $df=2$, $p=0.91$) on the number of recaptures existed in 2008. In 2009, there was again no difference in the number of recaptured Florida Sand Skinks among treatments ($F=1.31$, $df=4$, $p=0.34$), but there was a significant difference among blocks ($F=6.56$, $df=2$, $p=0.021$). The randomized block design does

not allow testing for a significant treatment-block interaction because of lack of replication within blocks, but Figure 18 graphically displays this relationship and suggests a significant interaction for the total recaptures.

Model comparison in MARK showed that recapture probability estimation was best when time-dependence was incorporated into the model ($\phi.P_T$) (Table 4). According to QAICc values and LRTs, the two models that incorporated variation in recapture probability between blocks and years ($\phi.P_{B \times T}$ and $\phi.P_{B \times T \times B \times T}$), were equally as parsimonious as model $\phi.P_T$. These three models were all significantly better than the null model, $\phi.P$, according to QAICc comparison and LRTs. These comparisons were made after adjusting \hat{c} to 1.69 because of lack of fit of the most parameterized model to the data. Based on these results, I decided to run three sets of candidate models to test for the effect of enclosure grouping on ϕ estimation: one set that allowed P to vary by year in each model ($\phi.P_T$), one set that allowed P to vary between years and blocks in each model ($\phi.P_{B \times T}$), and another that included block and time variation in P estimation as well as its interaction ($\phi.P_{B \times T \times B \times T}$). When performing the GOF bootstrap test of models $\phi_E P_{B \times T}$ and $\phi_E P_{B \times T \times B \times T}$, the most parameterized models of the latter two sets, the lack of fit was too severe to include them. I proceeded using only the model set that incorporated time-dependence in P estimation, whose most parameterized model ($\phi_E P_T$) adequately fit the data after adjusting \hat{c} to 1.82.

The model that varied ϕ estimation by block ($\phi_B P_T$) was equal in parsimony to the null model ($\phi.P_T$) in which only one estimate of survival rate was generated for the entire population (Table 5). Each of these models was significantly better than models that incorporated treatment ($\phi_R P_T$) or treatment and block together ($\phi_{R \times B} P_T$) according to QAICc values. These models were, in turn, significantly more parsimonious than one that estimated ϕ for each enclosure ($\phi_E P_T$). Because all models were equally or less parsimonious than the null model ($\phi.P_T$), it can be inferred that there was no effect of treatment or block on survival. The ϕ estimates and 95% confidence intervals generated by MARK were plotted for models $\phi_R P_T$, $\phi_{R \times B} P_T$ and $\phi_E P_T$ (Fig. 19).

Of the models that separated enclosures into two groups based on the presence or absence of coarse woody debris, shade, or trees (Table 6), the model that accounted for shade

($\Phi_{\text{shade}}P.$) was significantly more parsimonious than the null model ($\Phi.P.$) according to QAICc values and LRT procedures. When time-dependence was incorporated into P estimation, the model that accounted for shade was the most parsimonious, but not at the level of significance seen when time-dependence was not incorporated into P estimation. The same c -hat was used for this set of models that was used for the models above. The two-way ANOVAs based on these groupings of enclosures also showed a significant effect of shade on the number recaptured Florida Sand Skinks ($F=7.59$, $df=1$, $p=0.02$). No significant effect of block ($F=0.75$, $df=2$, $p=0.50$) or interaction ($F=2.50$, $df=2$, $p=0.14$) exists for this comparison. For the total number of recaptures within years, the effect of shade on recaptures was seen in 2008 ($F=8.19$, $df=1$, $p=0.02$) but not in 2009 ($F=2.79$, $df=1$, $p=0.13$).

Effect of Environment

Spearman correlation coefficients revealed a significant negative relationship between the recapture rate (totaled over both years) and the average soil moisture in each enclosure ($\rho=-0.53$, $p<0.05$) (Fig. 20). A significant negative correlation also existed between recapture rate and the percent of time the temperature readings were within the Florida Sand Skink's preferred temperature ($\rho=-0.55$, $p<0.05$). Similarly, of the models run in MARK that used the enclosure averages of the environmental variables as covariates to constrain Φ estimation (Table 7), the same two variables were the only ones that improved model parsimony over the null model ($\Phi.P_T$). Only the model that accounted for soil moisture was significantly different from the null according to QAICc comparison and LRT. Model comparisons were made after c -hat was adjusted to 1.82 based on the goodness of fit of the most parameterized model $\Phi_E P_T$.

Effect of Sex, Age Class, and Size

Of the 300 Florida Sand Skinks released into enclosures at the recipient site, 195 of them were males, 88 were female, and 17 were juveniles. Although there was variation in sex and age ratios within each enclosure, all enclosures received more males than females and more females than juveniles (Table3). Females, males, and juveniles had recapture rates of 30.3%, 36.1%, and

47.1%, respectively. The arrangement of the data for the corresponding MARK analysis caused a significant lack of fit, and therefore models were not run in MARK. However, a Kruskal-Wallis analysis of variance revealed significant differences in size between these groups (Fig. 21), based on both SVL ($H=74.56$, $df=2$, $p<0.01$) and mass ($H=69.85$, $df=2$, $p<0.01$). Mann-Whitney U test used for post-hoc comparisons showed that females were significantly larger than males (SVL, $U=5102.0$, $df=1$, $p<0.01$; mass, $U=5434.0$, $df=1$, $p<0.01$) and males were significantly larger than juveniles (SVL, $U=15.0$, $df=1$, $p<0.01$; mass, $U=11.0$, $df=1$, $p<0.01$).

No significant difference exists between the mass ($U=9602.5$, $df=1$, $p=0.38$) or SVL ($U=8920.0$, $df=1$, $p=0.07$) of Florida Sand Skinks that were recaptured and those that were not. When size was incorporated into models in MARK (c -hat adjusted to 1.69), no model was significantly more parsimonious than the null model (Table 8).

Effect of Trap Location

The recapture rates of Florida Sand Skinks captured at each site within the donor site are as follows: 35.8, 35.6, 30.9, and 37.1% for each of the four larger sites and 42.9 and 20% for each of the two smaller sites. The number of individuals from each site released at the donor site into each enclosure can be found in Table 3. After adjusting c -hat to 2.57 to account for lack of model fit to the data ($\Phi_{\text{trap site}} P_T$), the null models in MARK were significantly more parsimonious than those that accounted for capture site (Table 9).

Reproduction

Thirty-two unmarked Florida Sand Skinks were captured in total, 15 individuals in 2008 and 17 individuals in 2009 (Figs. 22 and 23). Four of the new juveniles captured in 2008 were recaptured in 2009. No effect of treatment ($F=0.54$, $df=4$, $p=0.71$) or block ($F=0.91$, $df=2$, $p=0.44$) on reproduction was found for the number of recruits totaled over both years. The number of new individuals found each year was also not significantly affected by treatment (2008, $F=1.24$, $df=4$, $p=0.37$; 2009, $F=0.28$, $df=4$, $p=0.89$). Furthermore, this lack of treatment effect was seen regardless of whether enclosures were grouped into five treatments or groups of two based on

the presence or absence of trees ($F=0.55$, $df=1$, $p=0.47$), shade ($F=0.95$, $df=1$, $p=0.35$), or wood ($F=0.90$, $df=1$, $p=0.36$). A significant negative association exists between the total number of new skinks found in each enclosure and the enclosure average for light intensity ($\rho=-0.52$, $p<0.05$) and penetrometer pressure ($\rho=-0.72$, $p<0.05$), indicating increased reproduction with loose soils and low light (Fig. 24).

Discussion

Donor Site

The pattern of Florida Sand Skink captures at the donor site exhibited aggregation, however their association with any one microhabitat feature is unclear. While there was a significantly positive correlation between the number of individuals captured at each array and array PC1 scores, one outlier calls this relationship into question (Fig. 11). The single array where the most Florida Sand Skinks were captured (nine individuals, Fig. 9) had a lower PC1 score than the average of arrays where no individuals were found. The first component arranged the trap arrays along a spectrum from low-lit areas containing trees (higher canopy cover) with woody debris and detritus under them at one end (low scores) to open, sunny areas with little to no groundcover at the other (high scores) (Fig. 10). Although overall more individuals were captured in the open, bare areas, one array surrounded by dead groundcover under a high tree canopy captured the most. The second principal component mainly described the groundcover, from bare ground at one end (low scores) to high vegetative groundcover at the other (high scores). Because there was no significant correlation between this component and the number of captures at each array, it can be inferred that within the open areas where individuals were most often found (PC1) the presence of vegetative groundcover had no influence on their abundance (PC2). This lack of aversion to vegetative groundcover was likely an important factor in their success at the recipient site (discussed below). A significant positive correlation exists between the percent of soil moisture and the number of captures at each array (Fig. 12). However, soil moisture was also positively correlated to PC1 scores at each array (Fig. 11), making it difficult to know which feature contributed to the number of captures. Furthermore, because of the significant negative correlation between soil moisture and recapture rate seen at the recipient site (Fig. 20), soil moisture may not be an accurate indicator of Florida Sand Skink presence.

Although the trapping efforts at the Davenport scrub resulted in the greatest number of Florida Sand Skink captures to date (Fig. 8 and 9), no habitat feature(s) strongly predicted where individuals would be captured the most. Nevertheless, based on the extensive sampling in this study, it is difficult to conclude that these results only add to the “confusion” about optimal Florida Sand Skink habitat. Instead, they likely support the inferences made by authors of previous studies that have also found no strong correlations between Florida Sand Skink density and specific microhabitat features (Hill 199, McCoy *et al.* 1999, Gianopulos 2001). Yet, which of these inferences my results support is unclear: (1) that this species does not have one optimal scrub or sandhill habitat type and is capable of thriving in a variety of conditions or (2) that heterogeneous scrub and sandhill ecosystems such as the donor site are optimal habitats? The donor site contained large open areas interspersed with areas of dense canopy cover and areas covered in grasses or palmettos (Fig. 2). The existence of these varying types of microhabitats within close proximity to each other may be necessary to meet the Florida Sand Skink’s locomotive, thermoregulatory, and nutritional needs, but the prevalence of individuals across all microhabitats within the donor site may instead indicate a general ability to thrive in all of them.

Recipient Site

Overall, habitat features within the enclosures at the recipient site differed from habitat features at the donor site. The component scores assigned to the recipient site data points based on the donor site PCA loadings categorized very few of the enclosures as comparable to the Davenport scrub habitat (Fig. 14). Scores from both components significantly differed between the sites. All of the enclosures, however, had scores that matched the donor site scores for at least one of the two principal components. In general, the enclosures that contained trees had a percentage of bare ground and live vegetative groundcover that was within the range seen at the donor site (PC2), while their amount of canopy cover and detritus exceeded donor site levels (PC1). The enclosures without trees had measures of canopy cover, detritus, bare ground, and light intensity similar to those at the donor site (PC1), but the amount of vegetative groundcover was greater (PC2).

Significant differences exist among replicates of treatments in the environmental variables measured (Table 2). The treatments without trees differed in the proportion of bare ground, vegetative groundcover, and detritus. Light intensity and soil compaction varied among treatments containing trees, likely the result of variation in the location of the tree(s) within each enclosure. Because the tree canopy did not cover the entire 20 m² area, some of these enclosures received more light than others. Similarly, the effect of the tree's root system was likely not evenly distributed throughout the enclosed space, resulting in differing levels of compaction. The "Wood" treatment enclosures had the most variation among them in environmental variables, and as a result they were not grouped with any other treatment in the clustering analysis, and were equally related to the two major groupings (Fig. 13). The "Control" enclosures were the only replicates not separated into these two groups. The group containing the "Control" replicates also contained one replicate from each of the other treatments (except "Wood"). Nevertheless, at least two of the replicates of each treatment were grouped together, allowing confidence in the effect of the assigned treatments on survival if one was indeed found. These differences among replicates, however, made an alternative analysis necessary, which tested for correlation between the number of recaptures and the environmental variables measured for each enclosure individually, ignoring treatments altogether.

Testing for variation in each environmental variable among treatments revealed that the enclosure manipulations resulted in differences beyond the presence or absence of trees, shade, and coarse woody debris (Table 1). For the two primary manipulations, the inclusion of trees and coarse woody debris, there were clear significant differences between those treatments with and without these features. Light intensity also differed, as expected, between the enclosures with trees or shade-cloth and those with neither (although "Shadecloth" and "Control" were not significantly different). No other variable showed these clear divisions. For instance, the depth the penetrometer reached before reaching highly compacted ground was greatest in the "Wood" and "Shadecloth" treatments (indicating looser soils), lowest in the "Tree" treatment, with the "Control" and "Tree+Wood" treatments not differing from either extreme. The percent of ground covered by detritus was greatest in the treatment with trees, lowest in the treatments without trees, and

intermediate in the “Shadecloth” treatment. Moreover, the percent of time that the ground temperatures were within the Florida Sand Skink’s preferred range did not differ between treatments.

Survival

The recapture of the translocated Florida Sand Skinks did not differ among the five treatments (Figs. 16 and 17). Similarly, no environmental variables were correlated with recaptures except soil moisture (Fig. 20) and the percent of time the ground temperature was within their preferred temperature during the activity season, whose contributions to success within the enclosures are questionable. Although significant according to Spearman correlation test, MARK analyses did not support the relationship between temperature and survival (Table 7). Secondly, the relationship was negative, indicating increased survival with more time outside of the preferred temperature range, an unlikely causal relationship. Additionally, there was no difference among treatments for soil temperature (Table 1), and thus, even if it was considered a contributing factor to their success, it cannot be attributed to any habitat feature in the enclosures. The significant negative correlation between recaptures and soil moisture was supported by MARK (Table 7), but the positive relationship between soil moisture and captures at the donor site (Fig. 12) makes it an unreliable predictor of success.

Significantly more recaptured Florida Sand Skinks were found in the enclosures without shade, either in the form of a tree or shade-cloth, when compared directly with the enclosures with shade. This division of treatments corresponds with the differences in measures of light intensity and soil compaction (measured as penetrometer pressure) (Table 1). As mentioned above, the differences between the two groups for these variables involve some overlap, but they are the only environmental variables measured that show this trend. While creating differences in light intensity between these two groups was one of the goals of the treatment manipulations, the differences in soil compaction was not expected. The non-shaded, more successful treatments had higher penetrometer pressure values in general than shaded treatments, indicating more compact soils. These same two measures were both associated with high PC1 scores at the

donor site, and this component was positively correlated with the number of captures per trap array. This finding indicates a similarity in the features associated with success at the translocation site and highly occupied areas of the donor site. Finally, an individual's chance of surviving, regardless of the enclosure in which it was released, was not affected by its size, sex, age, or where was captured at the donor site.

Reproduction

The number of unmarked juveniles found within enclosures did not significantly differ among treatments or blocks or between any two groups of treatments (such as those with and without shade) (Figs. 22 and 23). Light intensity and penetrometer pressure were the only two environmental variables correlated with the number of individuals born in each enclosure, and it was a significantly negative relationship in both cases (Fig. 24). These are the same two variables that were significantly higher in the enclosures without shade, where recapture rates were also higher. This relationship suggests that the factors that contribute to survival can negatively influence reproduction for this species, a notion that has not been supported by any study. The significant correlations found between the number of new juveniles and light intensity and soil compaction measurements within each enclosure are likely the result of low numbers of new juveniles found in each enclosure (between zero and five) and the number of statistical tests performed.

Measures of Success/Recommendations

Although few of the treatment manipulations and microhabitat features measured could be directly associated with increased recapture rate within enclosures, it is not for lack of survival. All 15 enclosures had recaptures during each trap year, and the overall recapture rate for the entire translocated population was 35.0%. Estimations of survival rate from models fit to the recapture data using the program MARK were as high as 69.3%. Furthermore, yearly recapture rate did not increase or decrease substantially between the first and second trapping years, and the time of highest capture frequency each year at the recipient site matched the period of

highest capture frequency at the donor site (Figs 8 and 15). The translocated population exhibited successful reproduction as well. Newly born individuals were found in at least one replicate from each treatment during both years, and the number of new individuals found did not differ greatly between years. The survival of juveniles born at the recipient site to sexual maturity was confirmed when 4 of the 15 new juveniles captured in 2008 were recaptured in 2009.

Previous reviews of translocation programs have measured success based on the establishment of a self-sustaining population that has been monitored for a sufficient amount of time for the viability of the population to be confirmed (Griffith *et al.* 1989, Dodd and Seigel 1991, IUCN 1998). A recent review by Germano and Bishop (2009) used two criteria to assess whether a self-sustaining population had been established as a result of translocation efforts: (1) evidence of successful reproduction at the donor site that resulted in “a substantial addition of new recruits to the adult population” and (2) monitoring for at least the length of time it takes for the translocated species to reach maturity. Based on these criteria, the translocation of the Florida Sand Skink discussed in this paper has been a success. After two years of monitoring, the number of new recruits was greater than 10% of the size of the initial translocated population. Because the sex ratio of the 20 individuals released into each enclosure was greatly skewed toward males (Table 3), this number of new juveniles found is even more significant. The 32 recruits found were the result of reproduction in only 82 females, corresponding to a 39% female birth rate. Currently, the published age at which Florida Sand Skink’s reach sexual maturity is 19 to 22 months (Telford 1959, Ashton 2005), but the population used in this translocation showed quicker maturation in males. Ejaculation upon palpation of the hemipenes occurred in the male individuals born in the enclosures in 2008 and recaptured in 2009, indicating sexual maturation within approximately 9 months of hatching. By either measure, the length of time the translocated population was monitored in this study was at least the length of time it takes for the Florida Sand Skink to reach sexual maturity.

For this species, the estimated survival rate is particularly important to take into account when measuring success. The Florida Sand Skink is highly elusive and difficult to detect because of its fossorial lifestyle and very small size (approx. maximum of 65 mm). While several

individuals were recaptured multiple times within a single trap year, many first time recaptures were still being found by the end of the trapping seasons, making the probability of missed recaptures likely. The high frequency of non-recaptured survivors was supported when more than half of the recaptures during the second year were not captured during the previous trapping season. Therefore, the recapture rate highly underestimates survival in this study. Survival rate after two years of monitoring, as estimated by Cormack-Jolly-Seber models in MARK, was likely between 50% and 70%, a level that suggests the Florida Sand Skinks ability to survive in the conditions within the enclosures at the recipient site.

As with the capture data at the donor site, the recipient site data supports one of two ideas about optimal Florida Sand Skink habitat: that it does not exist or that heterogeneity is the most important characteristic. Their ability to survive and reproduce equally well in each of the five treatments supports the former notion. Not only were the habitat features in these treatments very different from one another (Table 1), but they were also generally different from the habitat features at the donor site (Fig. 14). The one common feature among enclosures and between the donor and recipient sites was structural heterogeneity. Yet, if heterogeneity were the most important factor for their success, one would assume that survival and reproduction would have been highest in enclosures with either trees or shade-cloth because of the naturally higher heterogeneity in these enclosures (see error bars in Fig. 14) caused by the presence of a shade-providing object that did not cover the enclosure entirely (Figs. 4 and 5). However, the non-shaded enclosures, which had generally higher recapture rates compared to shaded enclosures, were heterogeneous on a smaller scale, with interspersed patches of grass, dead vegetation, and bare ground. Heterogeneity at this scale may be all that is necessary for Florida Sand Skink survival, and perhaps this smaller-scale heterogeneity contributed to the greater survival in these enclosures. Live vegetation, whether tall trees or thick grasses, may serve the same functions of providing shade and refuge, retaining moisture, and attracting prey insect species. Hill (1999) found that the presence of a single vegetative stratum, either from trees or understory vegetation, was associated with Florida Sand Skink density in the wild. The presence of both understory and tree canopy together, however, was not associated with the presence of Florida Sand Skinks,

most likely because it does not provide heterogeneity caused by the lack of interspersed open, bare areas. The results from the donor and recipient sites support this. First, areas with both an understory and a tree canopy did not exist at the highly populated donor site. Moreover, this type of microhabitat was recreated at the recipient site in the “Shadecloth” treatment enclosures, which contained dense grass cover as well as a simulated canopy. My data reveal that Florida Sand Skinks were found in the bucket-traps underneath the shade-cloth only twice out of 55 total captures (not unique recaptures) in “Shadecloth” enclosures.

The ability of Florida Sand Skinks to survive where there are no layers of vegetation or canopy is an important consideration for future translocation programs because this type of area may be available for possible recipient sites. While many of the Florida Sand Skinks captured at the donor site were found in open, bare areas, these areas were always adjacent to areas with grass, shrub, or tree cover indicative of the patchy nature of the Davenport scrub (Fig. 2). This observation cannot confirm the ability of this species to survive for long periods with no vegetative cover. Although none of the recipient site enclosures could be placed in this category according to the environmental variables measured, survival in bare, open habitat was seen in this study. Because the environmental variables were measured during the second trapping year, the fact that the enclosures without trees contained little to no vegetative cover at the time the Florida Sand Skinks were released into them was not represented in the data. These bare, open conditions persisted in these enclosures for approximately six months until the rainy season promoted the rapid spread of grasses throughout the sunny areas, probably in response to the disturbance of soils during the installation of the enclosures in the months prior to the translocation. The grasses remained for the remainder of the study, but some conclusions can be drawn from this short time period before they spread. There was no sign of decreased survival or reproduction in these enclosures the following year compared to the shaded enclosures. Instead, these two enclosures without shade had significantly more recaptures than those with shade, an effect seen during this first year but not the second. This trend is most astonishing when considering that: (1) the months after their release until the rainy season are the hottest of the year (May, June, and July), (2) this period was probably the most critical in terms of the stress put

on the animals caused by the translocation, and (3) this time coincided with maternal brooding of eggs and juvenile emergence from the nests. The fact that neither survival nor reproduction suffered during this period indicates that Florida Sand Skinks are able to thrive in this microhabitat at least on a short-term basis. But was long-term success in these enclosures dependent on the grass that eventually grew because of the apparent need for heterogeneity? If grass had not grown and long-term survival was recorded in these enclosures, the importance of structural heterogeneity resulting from a single stratum of vegetation would be refuted. Instead, it would seem that the presence of at least some open, bare areas would be the most important factor for Florida Sand Skink success rather than heterogeneity.

While the data gathered for this experiment cannot answer this question, it is worth noting that vast expanses of bare, open areas are not found in the scrub and sandhill habitats on the Lake Wales Ridges or other ridges in central Florida. They are always interspersed with areas of vegetation. Therefore knowing the answer to the above question is not necessarily important when choosing how a reclaimed scrub will be altered to make translocated Florida Sand Skink survival more likely because the aim of reclamation should be to re-create habitat conditions similar to the original environment. The recipient site in this translocation differed from the donor site in the overall level of vegetative cover, whether in the form of trees or grasses. Also, species composition did not match that of the donor site, as this was not the goal of the treatments given to the enclosures. Despite these differences, structural heterogeneity in the form of a single stratum of vegetation was present throughout the recipient site, and this heterogeneity likely contributed to the overall success. Woody debris was provided, but had no effect on success because features associated with the vegetation seemed to adequately perform the functions of providing refuge, moisture, and prey.

Future translocation efforts involving the Florida Sand Skink should focus on providing open, bare areas interspersed with areas of a single vegetative stratum. Sites with this structural heterogeneity should be considered as recipient sites before sites that contain thick vegetative structure, with both an understory and canopy but no bare ground. This study shows that the presence of all of the same structural features found at a donor site will be an adequate indicator

of quality of the recipient site, even if the proportion of each of those structural features is not the same at each site. Therefore, the measurement of these features at each site is recommended.

Overall, the relationship between captures and microhabitat at the donor site and success at the recipient site show that the Florida Sand Skink can thrive in multiple differing microhabitat types and that heterogeneity in and around these microhabitats is important. Therefore, the conclusions of other researches studying this species can be synthesized into a common hypothesis: optimal Florida Sand Skink habitat does not exist because the necessary structural heterogeneity can be found on the microhabitat level in a multitude of habitat types. Gianopulos (2001) came to a similar conclusion. The Florida Sand Skink's morphological specialization, limited geographic range, and elusiveness in the wild all lead to the assumption that it is a habitat specialist. It seems, though, that the Florida Sand Skink is able to take advantage of several scrub and sandhill habitat types within its range, which contributed to its success across all of the microhabitat types provided at the recipient site in this experiment.

Figures

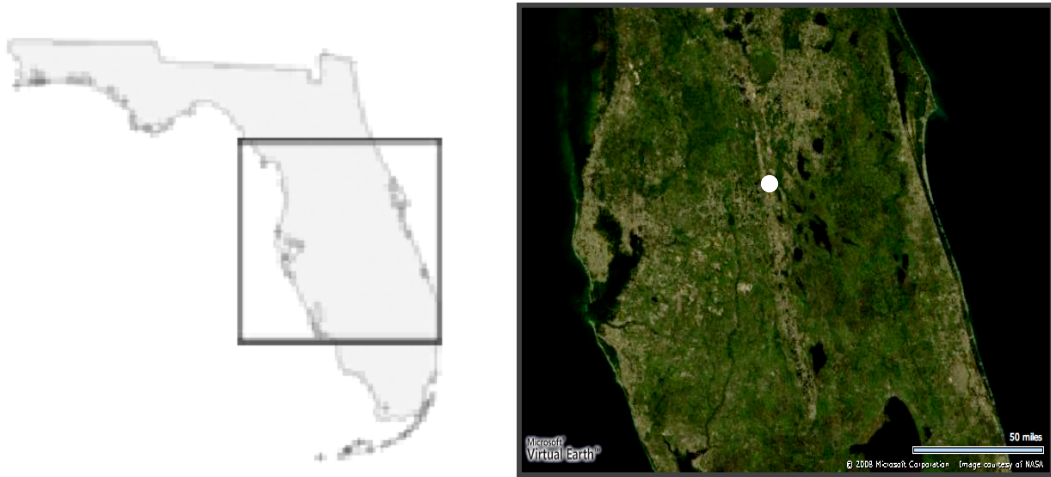


Fig. 1. Donor and recipient site location in central Florida. The Lake Wales Ridge runs down the center of central Florida, and the white dot denotes the area of the donor and recipient sites (approx. 24 km apart).

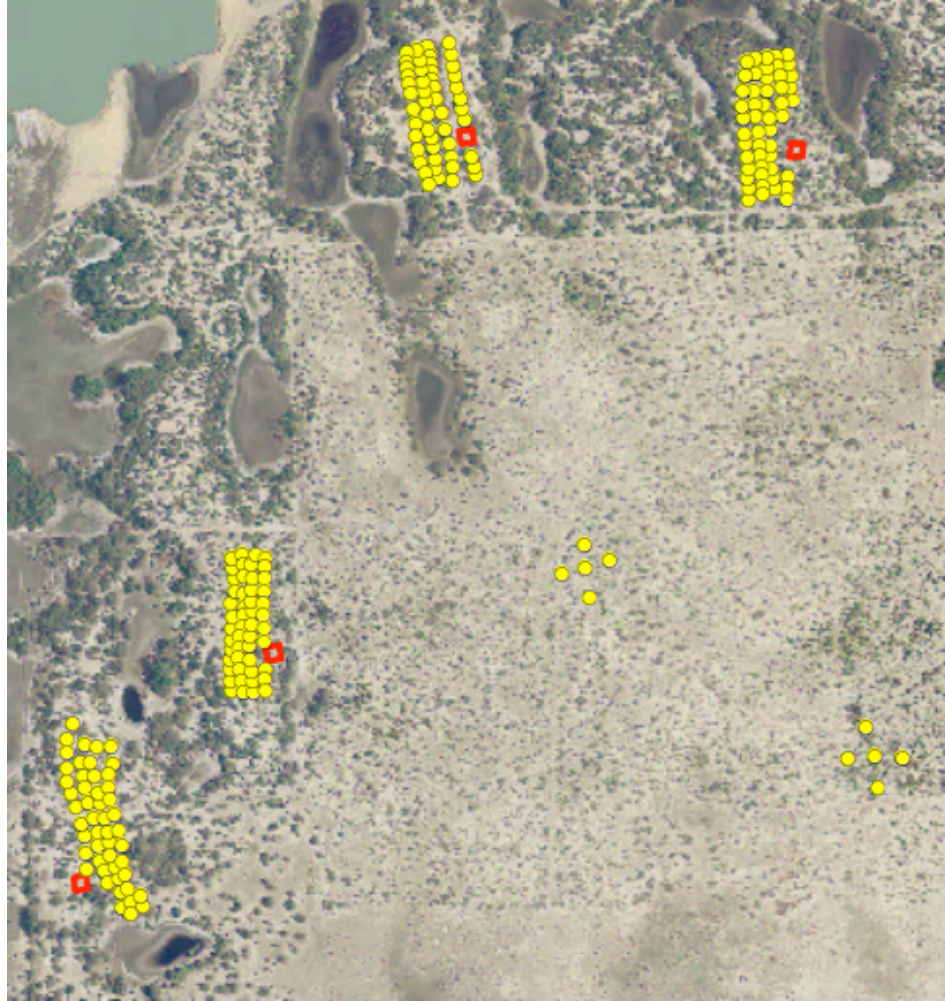


Fig. 2. Trap array locations at the donor site. The 210 trap arrays were divided among six sites throughout the approximately 1.2 km² scrub habitat near Davenport, FL. The large body of water in the upper left corner of the photo is part of the mining operation, which would eventually spread to capture sites. Photo by Aerials Express courtesy of ENTRIX Inc.

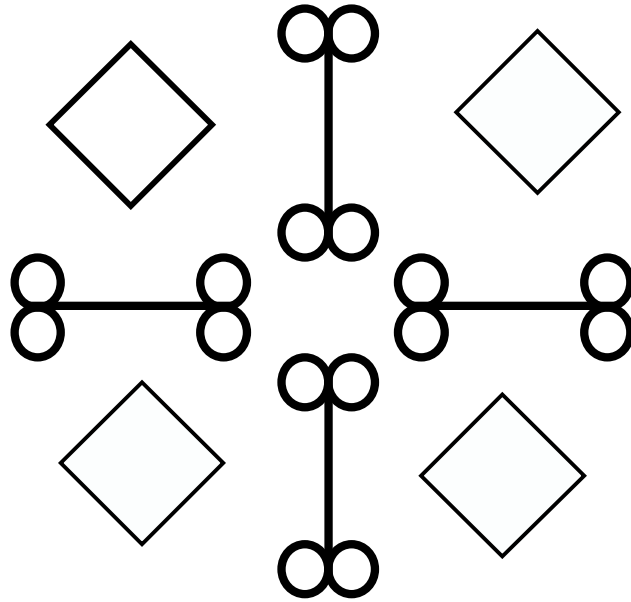


Fig. 3. Schematic of trap arrays at donor site. Each trap array consisted of four two-meter drift fences with two countersunk buckets at either side of each, totaling 16 one-gallon buckets per array (represented by circles). Each array was approximately 8 m² in size. The squares mark the placement of 1 m² quadrats for groundcover, canopy height, and light intensity data collection.

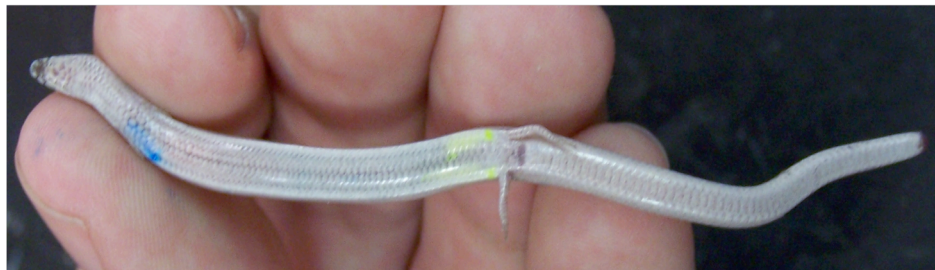


Fig. 4. Example of a marked Florida Sand Skink. A plastic polymer was injected under the skin in three of six possible locations using a combination of four possible colors. Each individual was given a unique marking that also indicated the treatment to which it was initially assigned.



Fig. 5. Photos of recipient site treatments. From left to right, they are: (1) no tree or woody debris (“Control”); (2) woody debris with no tree (“Wood”); (3) woody debris and shade from tree (“Tree+Wood”); (4) shade from tree but no woody debris (“Tree”); and (5) shade from elevated Shadecloth (“Shadecloth”).



Fig. 6. Arrangement of treatment replicates at recipient site. Fifteen 20 m² enclosures were divided among five treatments. A randomized block design was used, in which each row of five enclosures includes one replicate from each treatment in different order.

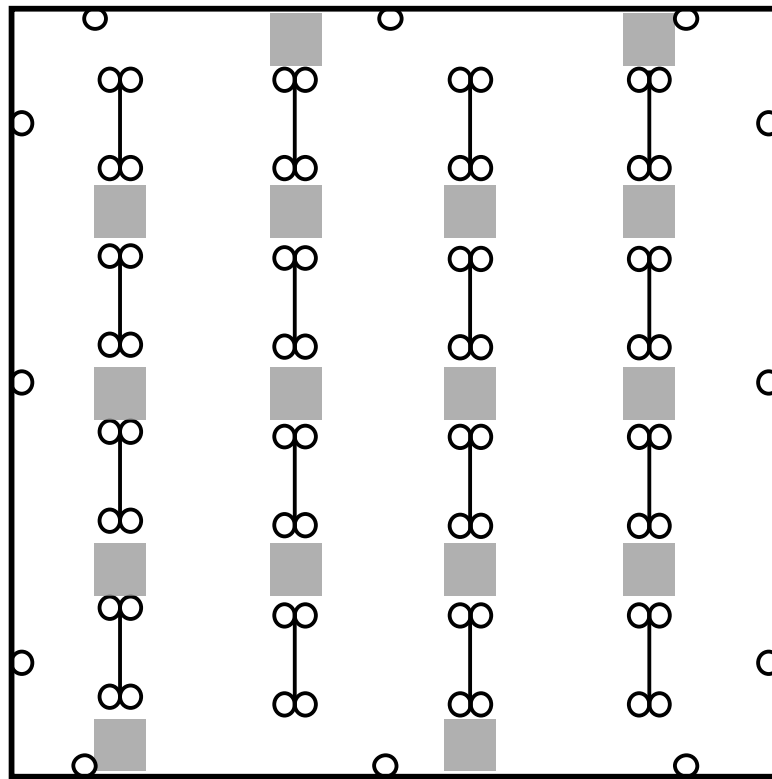


Fig. 7. Schematic of enclosures at the recipient site. Each circle represents a one-gallon bucket-trap (76 total), which was either positioned along the perimeter or at either end of a 2 m drift fence. The gray squares show where a 1 m² quadrat was laid for groundcover, light intensity, and canopy height data collection.

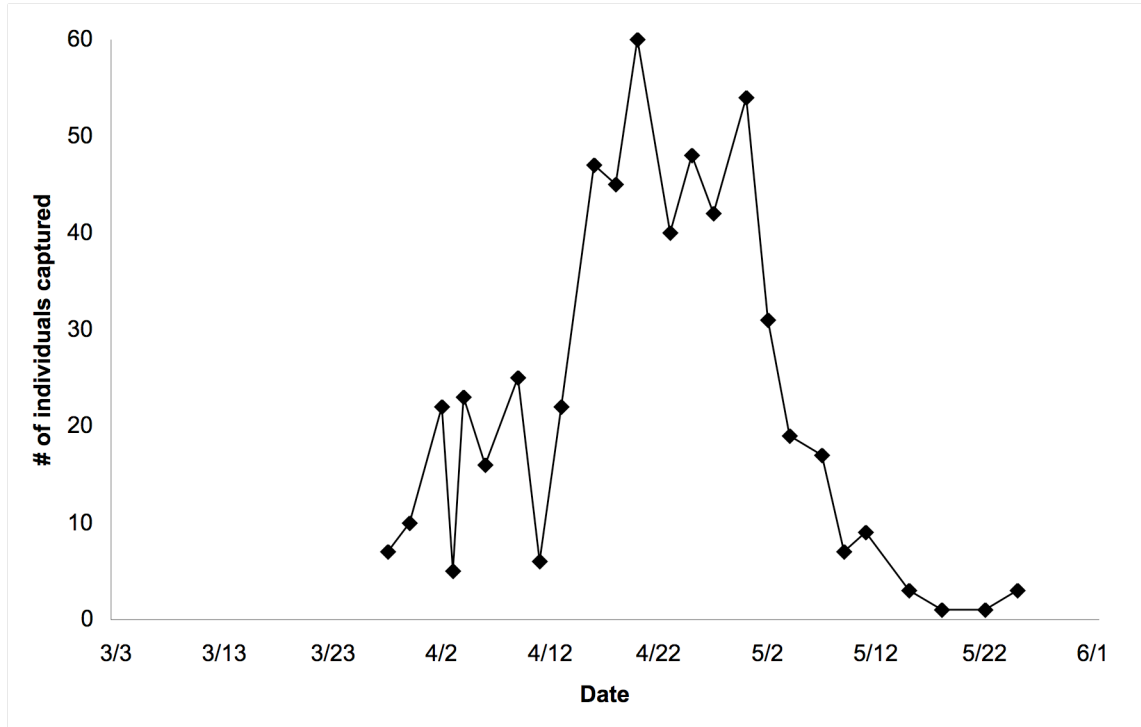


Fig. 8. Capture frequency at the donor site in 2007. All traps at each of the six areas of the donor site were checked at each capture event. The time of peak capture frequency corresponded to the time of peak capture frequency at the recipient site in 2008 and 2009 (Fig. 15).

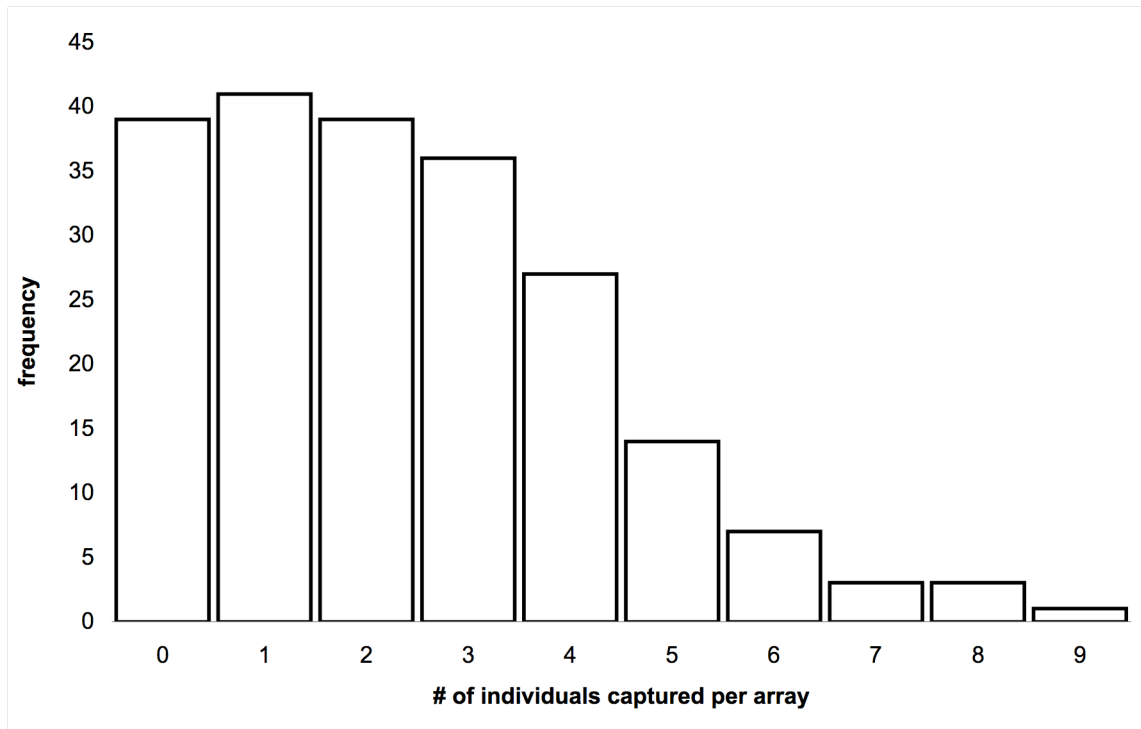


Fig. 9. Distribution of Florida Sand Skinks captured per trap array at the donor site. Five hundred and ten individuals were captured at 171 of the 210 trap arrays.

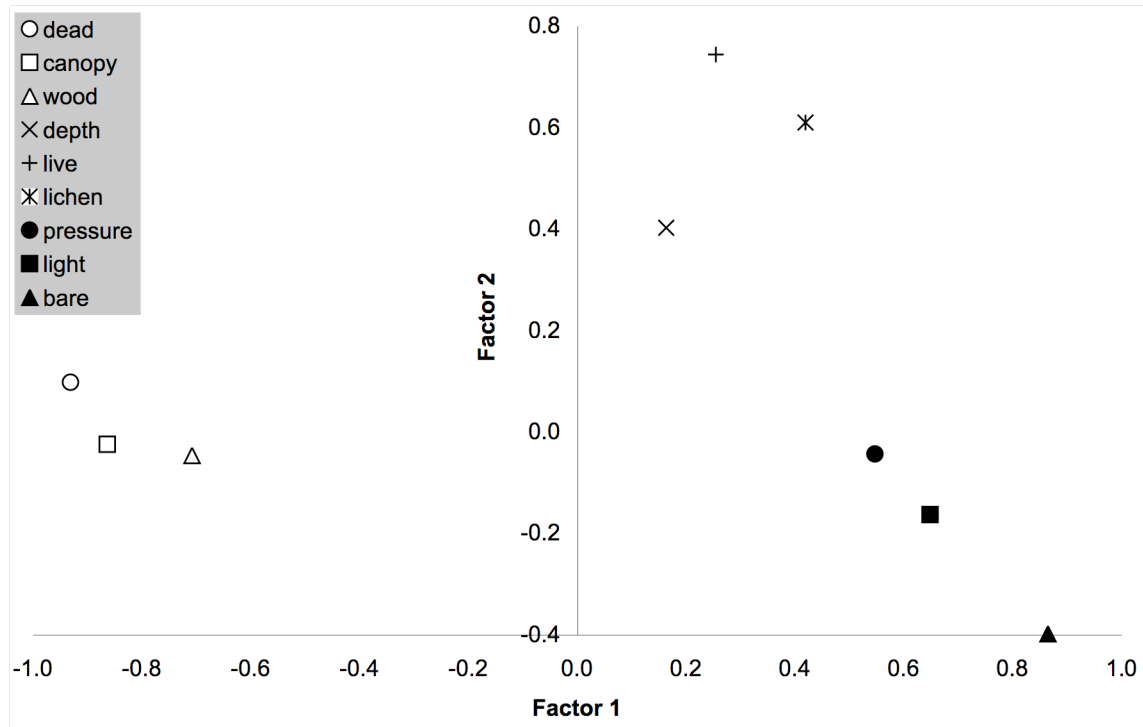


Fig. 10. PCA loadings for each variable using donor site environmental data. The first two components accounted for 57% of the variation in the data.

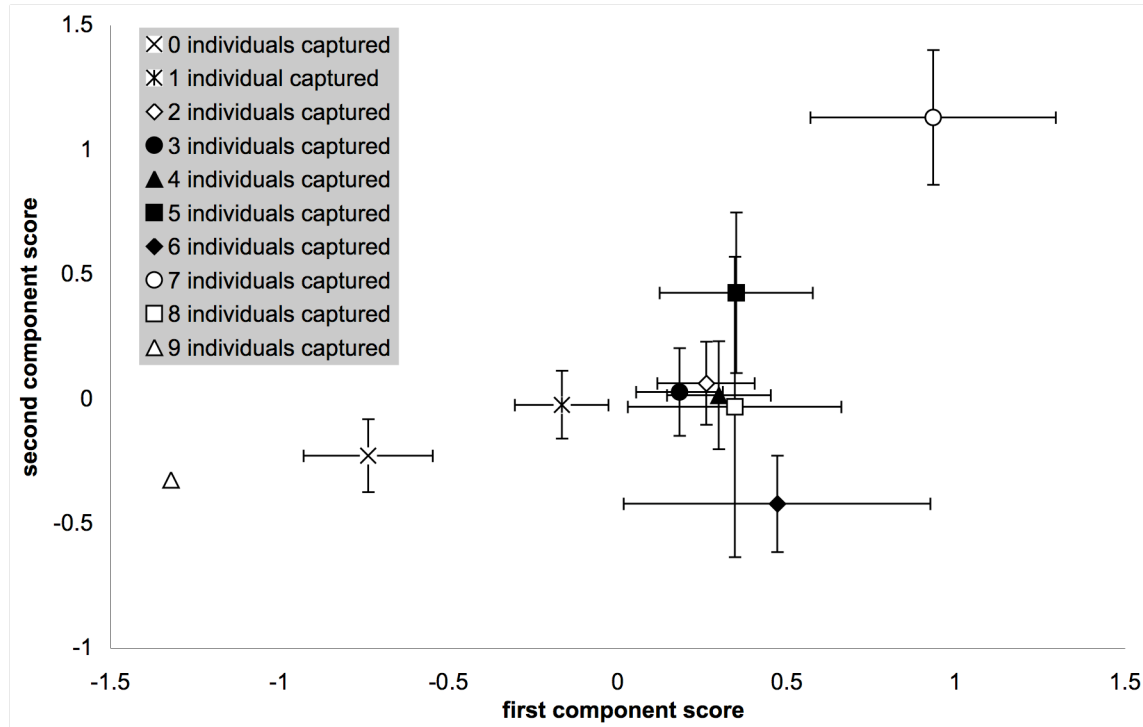


Fig. 11. Principal component scores for trap arrays at the donor site. Each point is the average (with standard error) for the arrays at which a certain number of individuals were caught. There was a significant positive correlation between the number of Florida Sand Skinks caught at arrays and PC1 scores (Wald $X^2=20.86$, $p<0.01$) but not PC2 scores (Wald $X^2=2.13$, $p=0.14$).

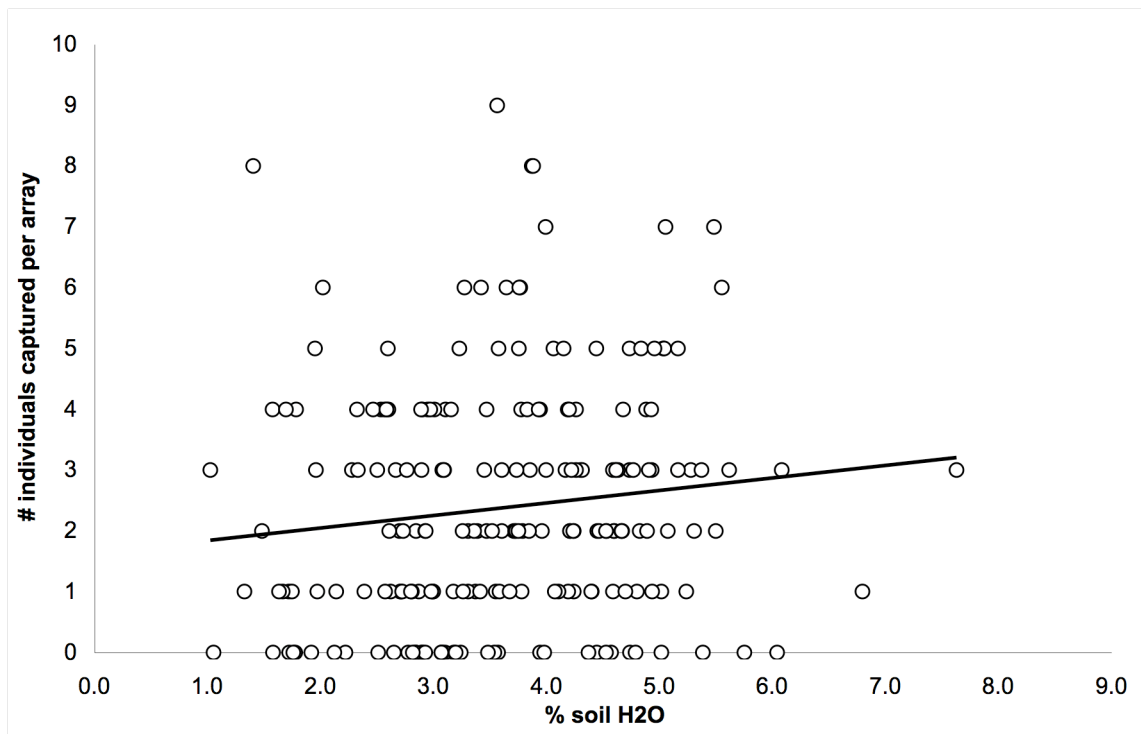


Fig. 12. Soil moisture and captures at the donor site. There was a positive (although not significant) relationship between the number of Florida Sand Skinks captured at each array and the % soil H₂O measured there (Wald $X^2=3.05$, $p=0.08$) determined by Poisson regression.

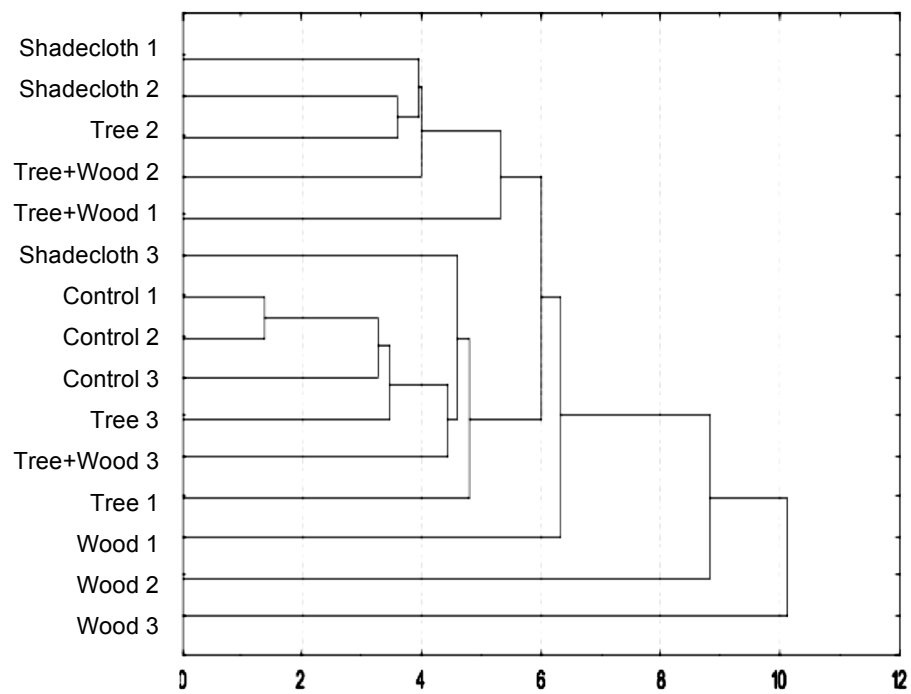


Fig. 13. Hierarchical clustering analysis using environmental data measured within enclosures. Euclidean distance was used to assess similarity for clustering.

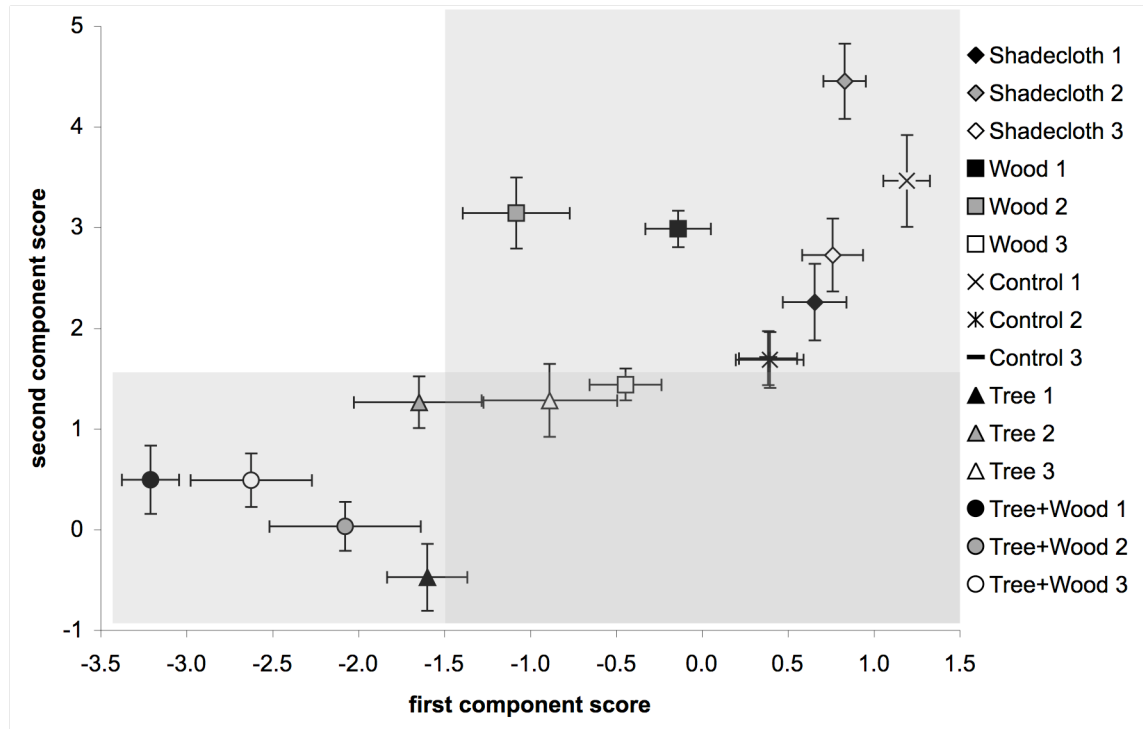


Fig. 14. PCA scores for enclosures used as supplemental cases. Enclosure averages (with standard errors) are shown for PC1 and PC2. The gray boxes indicate the range of scores occupied by the donor site trap array on each axis. The recipient site had significantly lower PC1 scores ($U=20791.0$, $df=1$, $p<0.01$) and significantly higher PC2 scores ($U=9446.0$, $df=1$, $p<0.01$) when compared with the donor site, according to Mann-Whitney U tests.

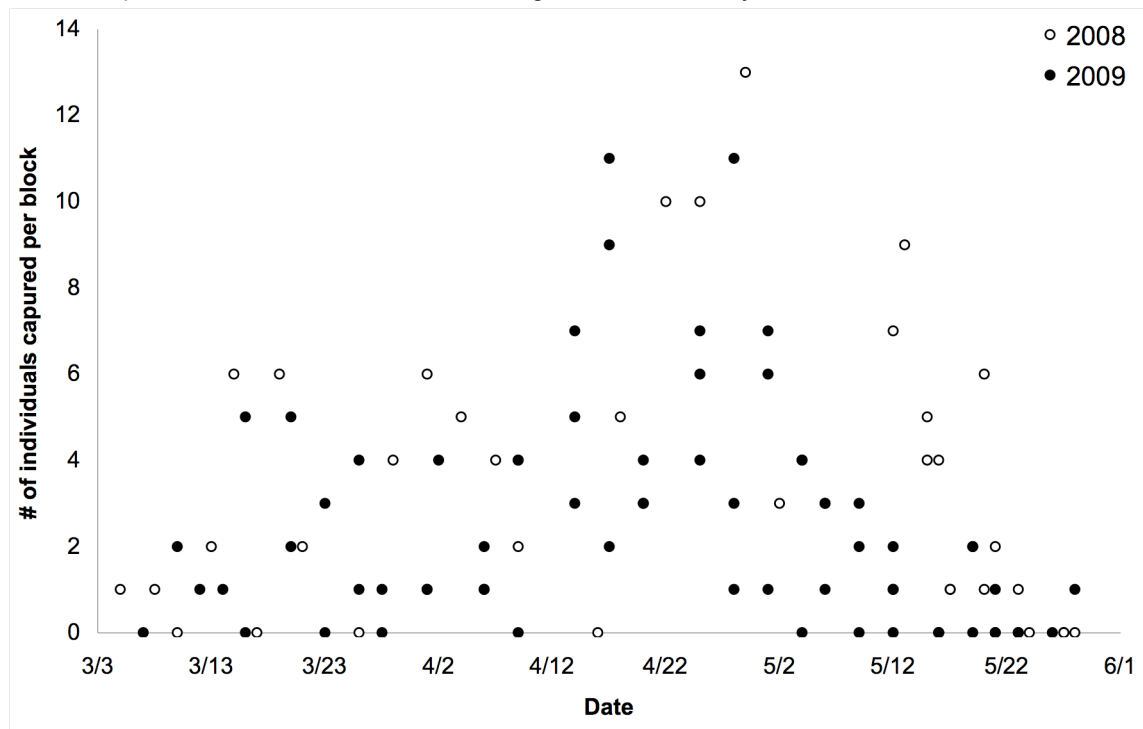


Fig. 15. Capture frequency at the recipient site in 2008 and 2009. Enclosures were checked in groups of five, one replicate from each treatment (i.e. block). Each point represents the number of skinks captured in one block in one day.

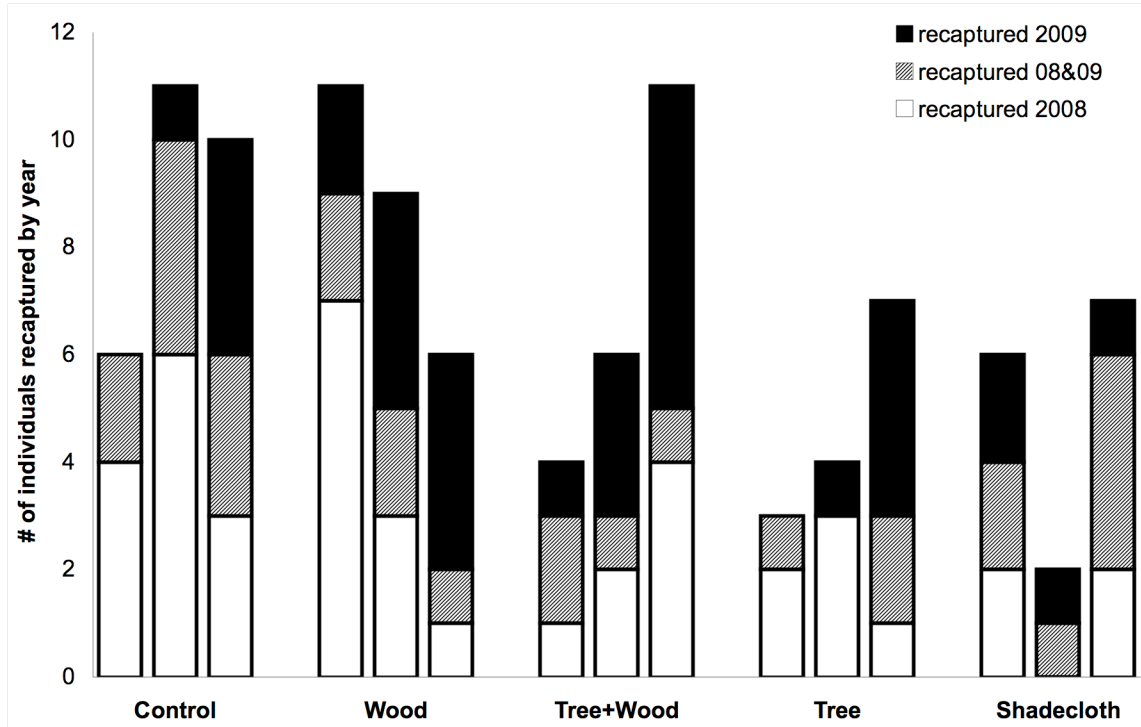


Figure 16. Recaptures of translocated Florida Sand Skinks by enclosure and year. Twenty individuals were translocated to each enclosure. There was no significant treatment ($F=1.57$, $df=4$, $p=0.27$) or block ($F=0.89$, $df=2$, $p=0.45$) effect on recapture rate, determined by one-way ANOVA.

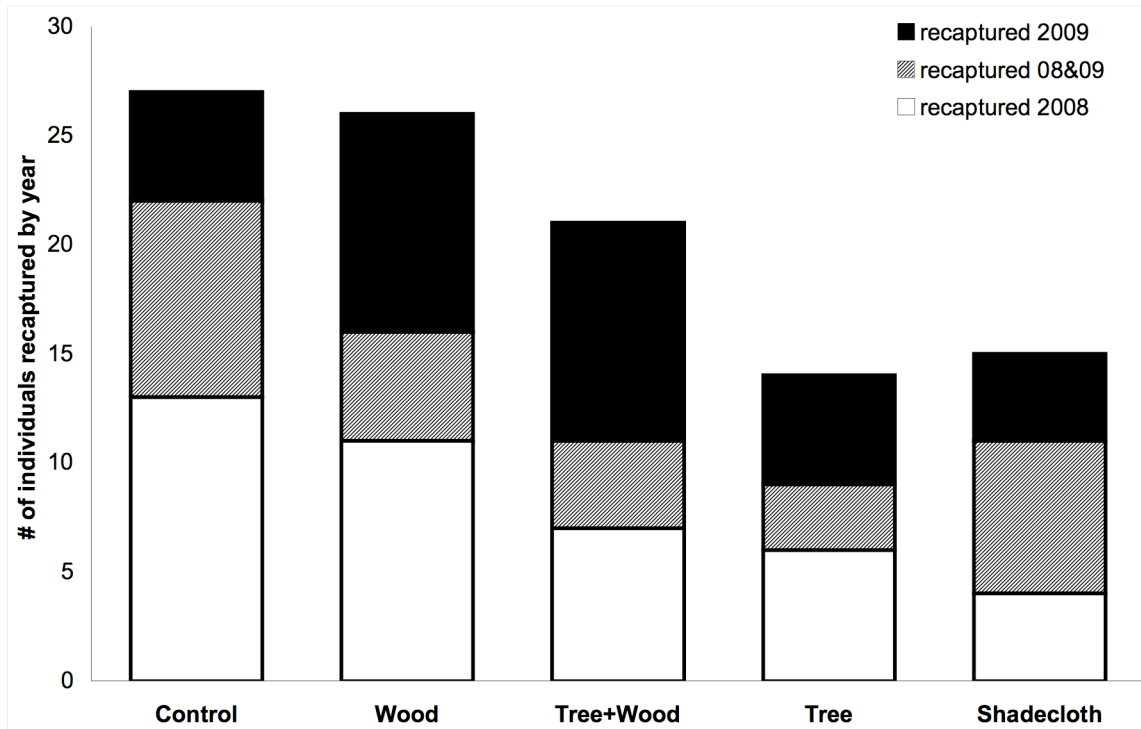


Figure 17. Recaptures of translocated skinks totaled by treatment. Enclosures that contained shade in the form of trees or shade-cloth had significantly less recaptures than enclosures without shade when treatments were grouped for this test (two-way ANOVA, $F=7.60$, $df=1$, $p=0.02$).

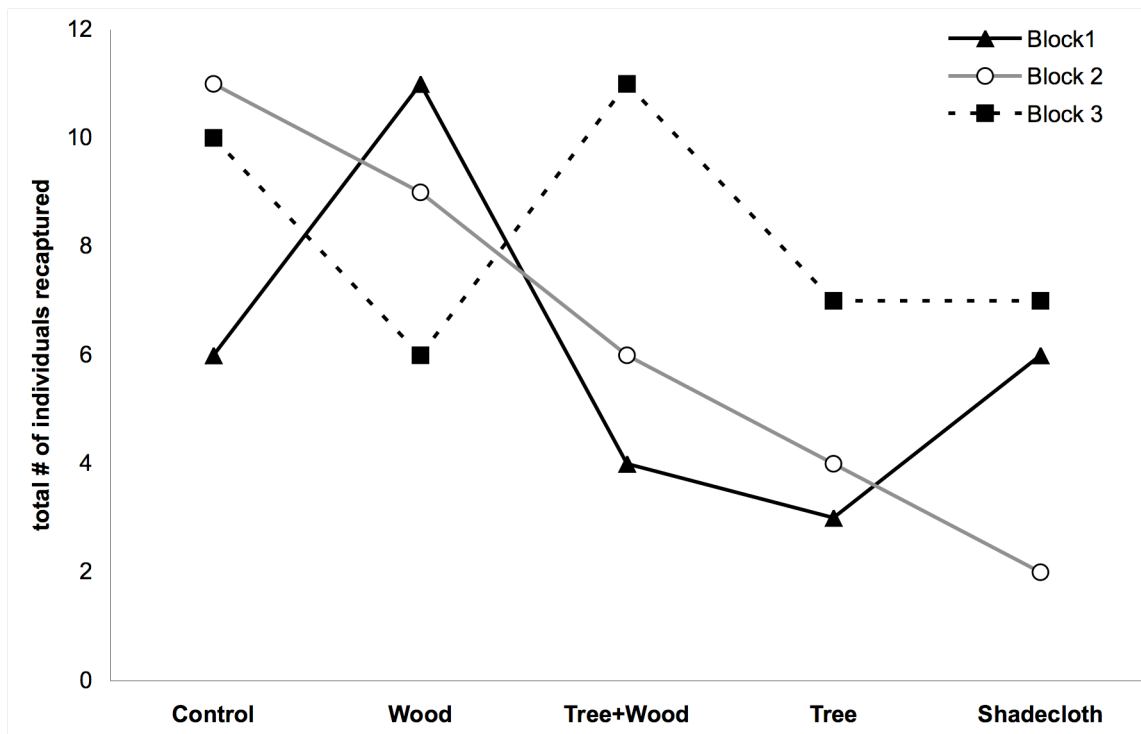


Fig. 18. The interaction between treatment and block for recaptures per enclosure. Because of the crossing of lines, an interaction effect can be inferred.

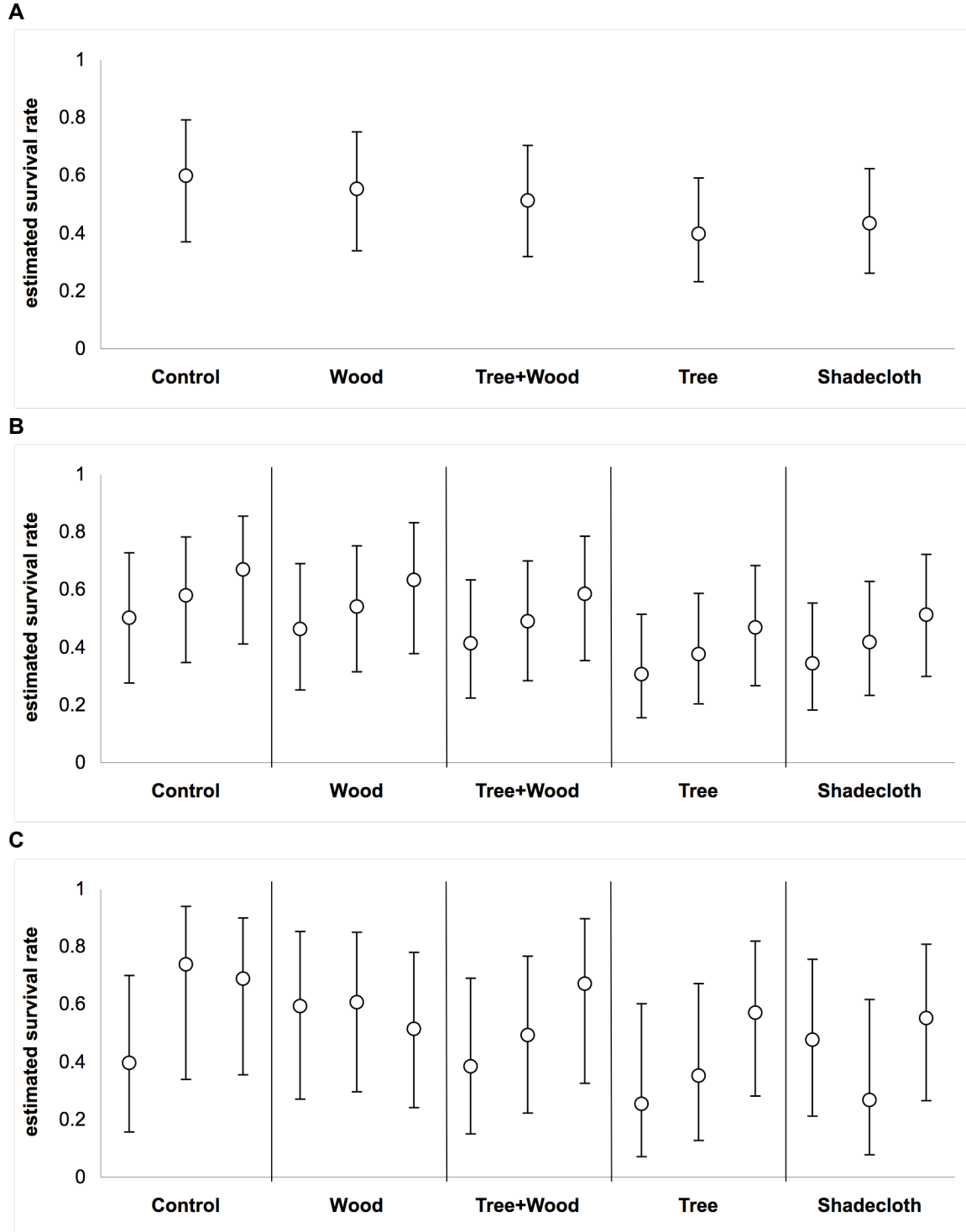


Fig. 19. Survival rate estimates (with 95% confidence intervals) from models $\phi_R P_T$ (A), $\phi_{R*B} P_T$ (B), and $\phi_E P_T$ (C). The second model's enclosure estimates are based on the assignment of each model to a treatment and block while the third model treats each enclosure individually. None of these models was more parsimonious than the null ($\phi.P_T$).

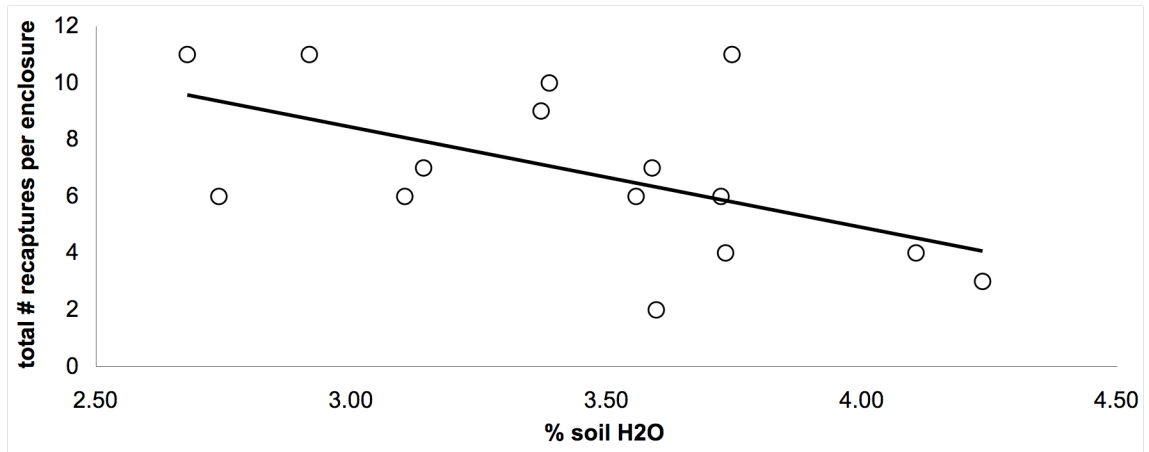


Fig. 20. Relationship between recaptures and soil moisture at the recipient site. Percent soil H₂O was the only variable that was significantly correlated with the number of recaptures within each enclosure (Spearman's $\rho = -0.53$, $p < 0.01$) and also supported by MARK analyses. The same correlation was significant at the donor site, except it was a positive rather than a negative relationship (Fig. 12). The line was added for visual clarity.

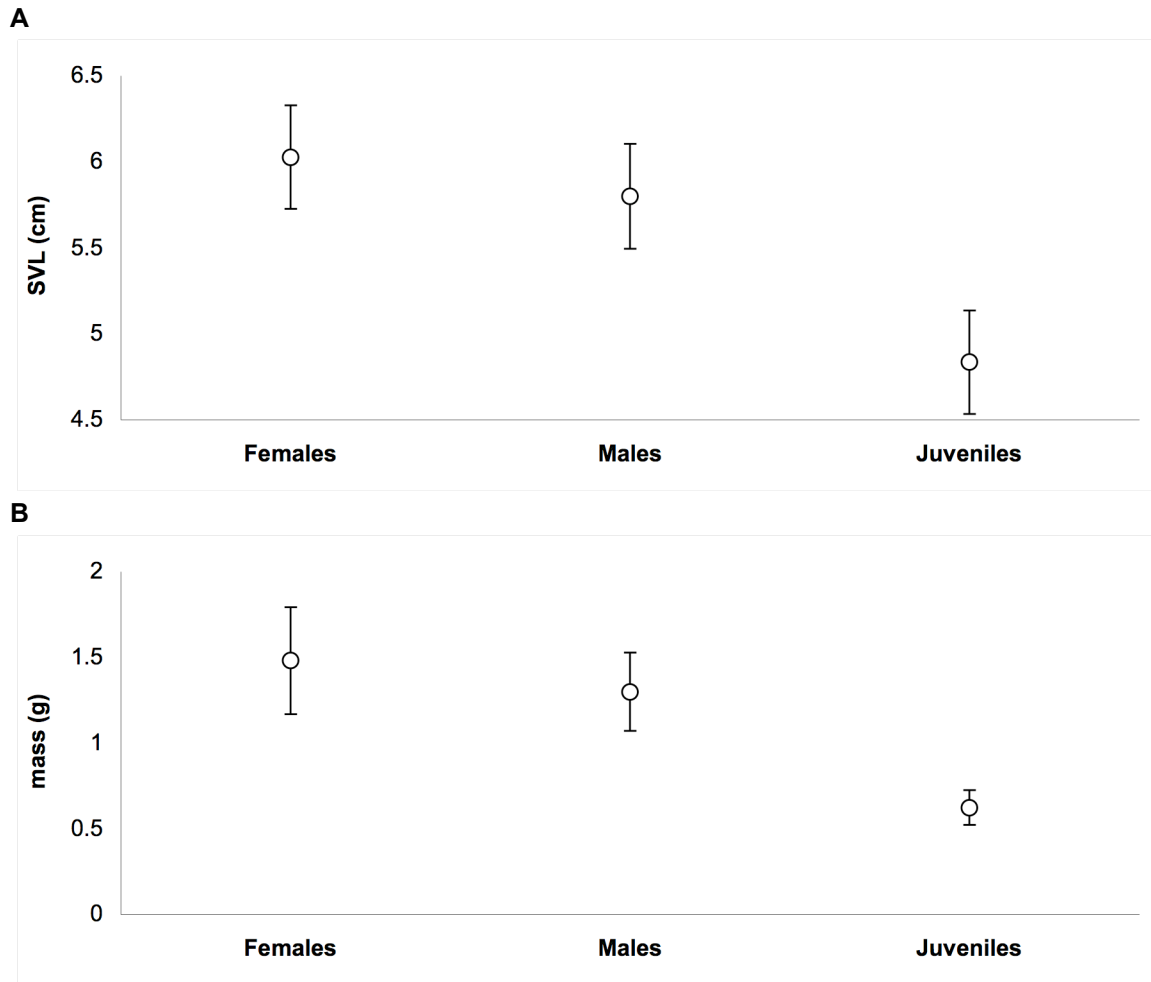


Fig. 21. Size of females, males, and juveniles translocated into enclosures. Kuskal-Wallace tests revealed significant differences between all groups for both SVL ($H=74.56$, $df=2$, $p<0.01$) (A) and mass ($H=69.85$, $df=2$, $p<0.01$) (B). All pairs were significantly different according to post-hoc tests. Error bars are one standard deviation of the mean.

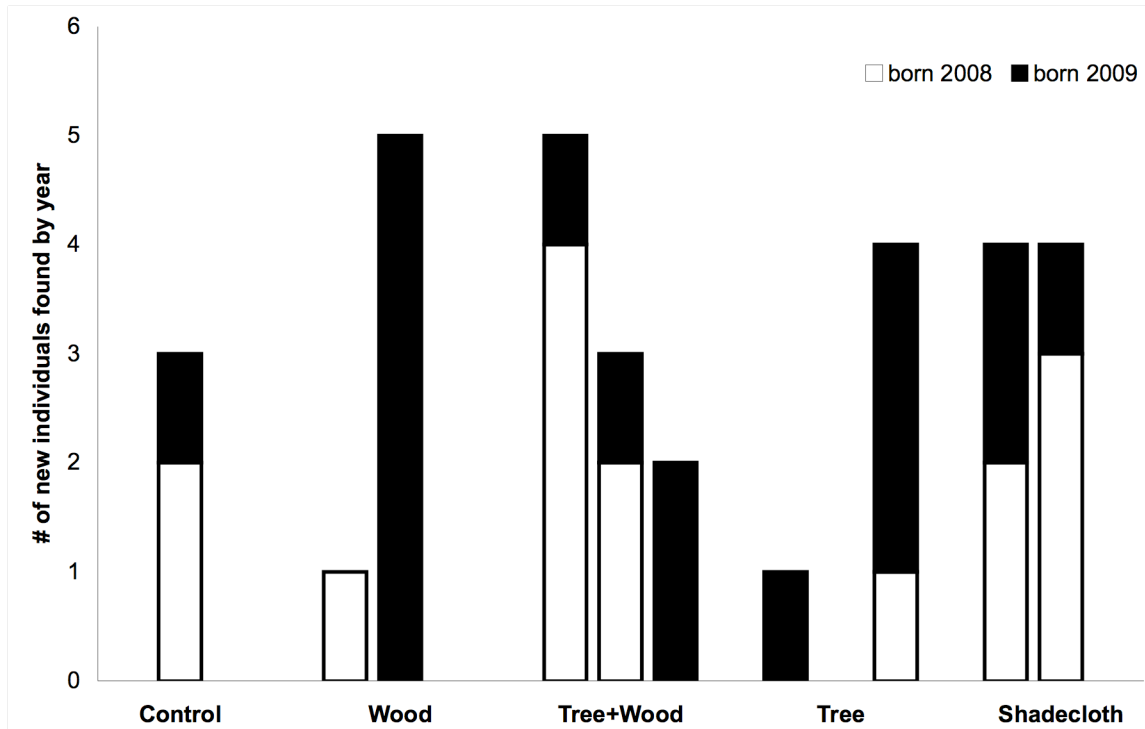


Fig. 22. Unmarked juvenile Florida Sand Skinks found in each enclosure by year. There was no effect of treatment (one-way ANOVA, $F=0.54$, $df=4$, $p=0.71$) or block (one-way ANOVA, $F=0.91$, $df=2$, $p=0.44$) on reproduction totaled for both years.

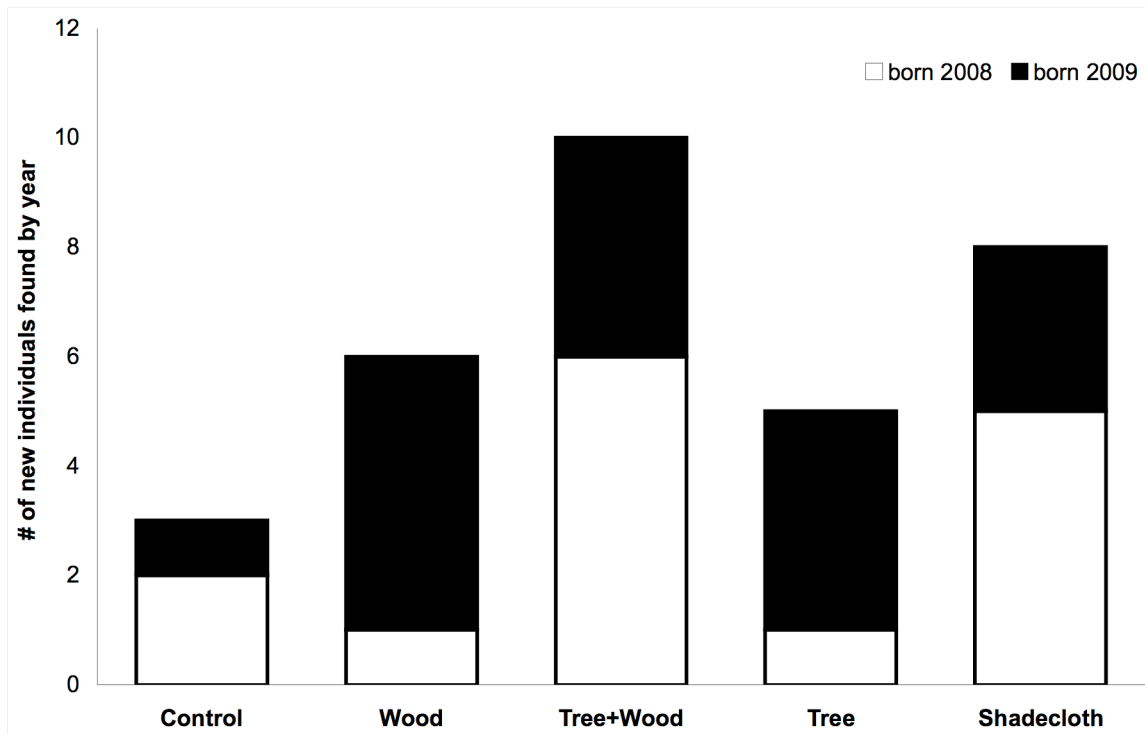


Fig. 23. Unmarked juvenile Florida Sand Skinks found in each enclosure totaled by treatment. An effect of treatment on reproduction was not seen for either year (one-way ANOVA; 2008, $F=1.24$, $df=4$, $p=0.37$; 2009, $F=0.28$, $df=4$, $p=0.89$).

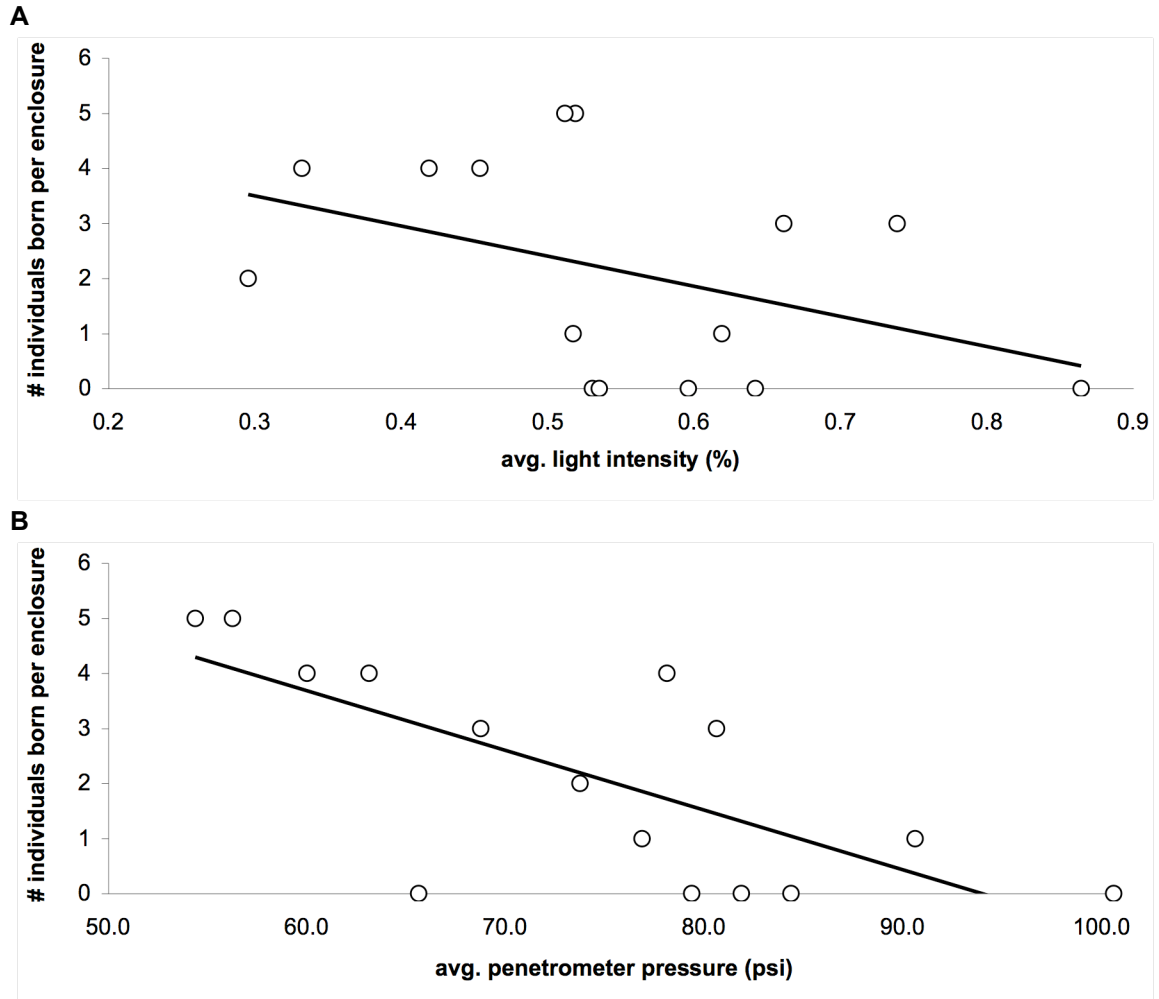


Fig. 24. Correlation between reproduction and environmental variables within enclosures. There was a significant negative relationship between the number of unmarked individuals found in each enclosure and (A) light intensity (Spearman's $\rho = -0.52$, $p < 0.05$) and (B) the amount of pressure exerted on the penetrometer (Spearman's $\rho = -0.72$, $p < 0.05$), indicating increased reproduction with loose soils and low light.

Tables

Table 1. Differences in environmental variables among treatments.

	Control	Wood	Tree+Wood	Tree	Shadecloth
Canopy Height					
Light Intensity					
Preferred Temperature					
Penetrometer Depth					
Penetrometer Pressure					
% Soil H₂O					
% Live Vegetation					
% Dead Vegetation					
% Bare Ground					
% Woody Debris					

Differences were determined using one-way ANOVA. Tukey's HSD was used for post-hoc comparisons. Differences were considered significant at the $p=0.05$ level. Differing colors indicate significant differences, with the black boxes signifying the highest values, gray boxes signifying intermediate values, and white boxes signifying the lowest values. Striped boxes indicate that the treatment was not significantly different from any of the treatments that contain the corresponding colors that make up the stripes.

Table 2. Differences in environmental variables among treatment replicates.

	Control	Wood	Tree+Wood	Tree	Shadecloth
Canopy Height	N/A	F=1.00 p=0.38	F=3.06 p=0.06	F=4.09 p=0.02	N/A
Light Intensity	F=0.35 p=0.71	F=7.12 p=0.00	F=14.08 p=0.00	F=5.29 p=0.01	F=0.97 p=0.39
Penetrometer Depth	F=0.25 p=0.78	F=9.48 p=0.00	F=5.76 p=0.01	F=6.26 p=0.00	F=2.36 p=0.12
Penetrometer Pressure	F=0.16 p=0.84	F=26.03 p=0.00	F=2.33 p=0.11	F=1.42 p=0.25	F=2.90 p=0.07
% Soil H₂O	F=1.73 p=0.26	F=6.00 p=0.04	F=0.11 p=0.90	F=0.27 p=0.77	F=2.49 p=0.16
% Live Vegetation	F=21.81 p=0.00	F=1.30 p=0.00	F=2.43 p=0.10	F=4.02 p=0.02	F=10.30 p=0.00
% Dead Vegetation	F=17.15 p=0.00	F=1.44 p=0.00	F=0.05 p=0.95	F=0.98 p=0.38	F=6.67 p=0.00
% Bare Ground	F=0.53 p=0.60	F=0.81 p=0.44	F=1.40 p=0.26	F=2.35 p=0.11	F=10.88 p=0.00
% Woody Debris	N/A	F=0.04 p=0.96	F=0.28 p=0.76	F=7.62 p=0.00	N/A

Differences were determined using one-way ANOVAs. For all tests, degrees of freedom = 2.

Table 3. Distribution of sex, age class, and capture locations of individuals relocated to each enclosure.

Enclosure	Sex/Age class ratios			Number from each area at donor site					
	# male	# female	# juveniles	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6
Shadecloth 1	14	6	0	6	6	3	5	0	0
Shadecloth 2	13	6	1	6	8	2	2	0	2
Shadecloth 3	15	4	1	6	4	2	7	1	0
Wood 1	12	7	1	6	8	1	5	0	0
Wood 2	14	4	2	4	7	5	4	0	0
Wood 3	15	4	1	3	3	8	6	0	0
Control 1	14	6	0	7	4	9	0	0	0
Control 2	12	7	1	2	11	0	4	3	0
Control 3	9	6	5	13	3	2	2	0	0
Tree 1	16	3	1	4	5	8	2	1	0
Tree 2	11	8	1	7	4	4	4	0	1
Tree 3	11	7	2	7	5	3	3	0	2
Tree+Wood 1	11	9	0	1	7	3	8	1	0
Tree+Wood 2	14	6	0	2	8	4	6	0	0
Tree+Wood 3	14	5	1	7	7	1	4	1	0
Total	195	88	17	81	90	55	62	7	5

Table 4. Models compared in MARK to assess the effect of enclosure grouping and time on recapture probability estimation (P).

Model Notation	Survival Rate Estimation		Recapture Probability Estimation			Model Parsimony					
	Grouping	Time	Grouping	Time	Group * Time Interaction	QAICc	Delta QAICc	QAICc Weights	Model Likelihood	Number of Parameters	QDeviance
ϕ, P_T	one	constant	one	varied	n/a	365.769	0.000	0.374	1.000	3	48.880
ϕ, P_{B^*T}	one	constant	block	varied	no	366.051	0.282	0.325	0.869	4	47.116
$\phi, P_{B^*T^*B^*T}$	one	constant	block	varied	yes	366.935	1.166	0.209	0.558	6	43.876
ϕ, P_{R^*T}	one	constant	treatment	varied	no	369.351	3.582	0.062	0.167	7	44.212
ϕ, P_{\cdot}	one	constant	one	constant	n/a	372.126	6.357	0.016	0.042	2	57.271
ϕ, P_R	one	constant	treatment	constant	n/a	373.647	7.878	0.007	0.020	6	50.588
$\phi, P_{R^*T^*R^*T}$	one	constant	treatment	varied	yes	375.135	9.366	0.003	0.009	10	43.685
ϕ, P_B	one	constant	block	constant	n/a	375.325	9.556	0.003	0.008	4	56.391
ϕ, P_{E^*T}	one	constant	enclosure	varied	no	382.543	16.774	0.000	0.000	17	35.937
ϕ, P_E	one	constant	enclosure	constant	n/a	384.732	18.963	0.000	0.000	16	40.328
$\phi, P_{E^*T^*E^*T}$	one	constant	enclosure	varied	yes	402.128	36.359	0.000	0.000	29	28.049

Models that incorporated differences between years and blocks were the most parsimonious and differed from the null (ϕ, P_{\cdot}).

Table 5. Model comparison for the effect of enclosure grouping on survival rate estimation (ϕ).

Model Notation	Survival Rate Estimation		Recapture Probability Estimation		Model Parsimony					
	Grouping	Time	Grouping	Time	QAICc	Delta QAICc	QAICc Weights	Model Likelihood	Number of Parameters	QDeviance
ϕ, P_T	one	constant	one	varied	340.076	0.000	0.472	1.000	3	45.389
ϕ_B, P_T	block	constant	one	varied	340.372	0.296	0.407	0.862	5	41.583
ϕ_R, P_T	treatment + treatment + block	constant	one	varied	344.083	4.007	0.064	0.135	7	41.145
ϕ_{R+B}, P_T	block	constant	one	varied	344.305	4.229	0.057	0.121	9	37.172
ϕ_E, P_T	enclosure	constant	one	varied	355.225	15.149	0.000	0.001	17	30.820

No treatment or block effect could be inferred because the null model was most parsimonious. The model that included the treatment-block interaction had the same outcome as model ϕ_E, P_T and is not included in this table. Survival rate estimates from three of these models are plotted in Fig. 19.

Table 6. Models testing the individual effects of the treatments given to enclosures on survival rate estimation (Φ).

Model Notation	Survival Rate Estimation		Recapture Probability Estimation	Model Parsimony					
	Grouping	Time	Time	QAICc	Delta QAICc	QAICc Weights	Model Likelihood	Number of Parameters	QDeviance
$\Phi_{\text{shade}} P_T$	shade	constant	varied	356.362	0.000	0.410	1.000	4	44.614
$\Phi_{\text{tree}} P_T$	one	constant	varied	357.452	1.090	0.238	0.580	3	47.750
$\Phi_{\text{wood}} P_T$	tree	constant	varied	358.452	2.090	0.144	0.352	4	46.705
$\Phi_R P_T$	wood	constant	varied	359.005	2.643	0.109	0.267	4	47.258
	treatment	constant	varied	361.238	4.876	0.036	0.087	7	43.286
$\Phi_{\text{shade}} P_{\cdot}$	shade	constant	constant	361.255	0.000	0.559	1.000	3	51.553
$\Phi_{\text{tree}} P_{\cdot}$	one	constant	constant	363.616	2.361	0.172	0.307	2	55.947
$\Phi_{\text{wood}} P_{\cdot}$	tree	constant	constant	364.257	3.003	0.125	0.223	3	54.555
$\Phi_R P_{\cdot}$	wood	constant	constant	364.896	3.641	0.090	0.162	3	55.194
	treatment	constant	constant	365.906	4.651	0.055	0.098	6	50.034

Survival rate was estimated for two groups of enclosures for each model based on the presence or absence of shade, trees, or woody debris. The model that grouped enclosures based on shade was significantly more parsimonious than the null, indicating an effect of shade on survival.

Table 7. Comparison of models incorporating enclosure averages of environmental variables into survival rate estimation (ϕ).

Model Notation	Survival Rate Estimation		Recapture Probability Estimation	Model Parsimony					
	Covariate	Time		QAICc	Delta QAICc	QAICc Weights	Model Likelihood	Number of Parameters	QDeviance
$\phi_{\text{water}} P_T$	soil H ₂ O	constant	varied	337.666	0.000	0.343	1.000	4	40.933
$\phi_{\text{temperature}} P_T$	temperature	constant	varied	339.368	1.702	0.154	0.427	4	42.636
$\phi_{\text{none}} P_T$	none	constant	varied	340.076	2.410	0.111	0.300	3	45.389
$\phi_{\text{canopy}} P_T$	canopy	constant	varied	340.144	2.478	0.098	0.290	4	43.412
$\phi_{\text{depth1}} P_T$	depth	constant	varied	341.318	3.652	0.064	0.161	4	44.585
$\phi_{\text{pressure1}} P_T$	pressure	constant	varied	342.027	4.361	0.048	0.113	4	45.294
$\phi_{\text{bare}} P_T$	bare ground	constant	varied	342.499	4.833	0.040	0.089	4	45.766
$\phi_{\text{light}} P_T$	light	constant	varied	342.634	4.969	0.038	0.083	4	45.902
$\phi_{\text{wood}} P_T$	woody debris	constant	varied	342.654	4.988	0.038	0.083	4	45.921
$\phi_{\text{live}} P_T$	live vegetation	constant	varied	342.657	4.992	0.028	0.082	4	45.925
$\phi_{\text{dead}} P_T$	dead vegetation	constant	varied	342.658	4.992	0.028	0.082	4	45.926
$\phi_E P_T$	none	constant	varied	355.225	17.559	0.000	0.000	17	30.820

The percent soil H₂O was the only variable that significantly increased model parsimony over the null after LRT and QAICc comparisons.

Table 8. Comparison of models with size-related individual covariates.

Model Notation	Survival Rate Estimation		Recapture Probability Estimation	Model Parsimony					
	Covariate(s)	Time		QAICc	Delta QAICc	QAICc Weights	Model Likelihood	Number of Parameters	QDeviance
ϕ, P_T	none	constant	varied	365.614	0.000	0.322	1.000	3	359.546
$\phi_{SVL} P_T$	svl	constant	varied	366.090	0.476	0.254	0.788	4	357.977
$\phi_{mass} P_T$	mass	constant	varied	366.355	0.742	0.222	0.690	4	358.243
$\phi_{SVL*SVL^2} P_T$	svl and svl ²	constant	varied	367.641	2.028	0.117	0.363	5	357.472
$\phi_{mass*mass^2} P_T$	mass and mass ²	constant	varied	368.284	2.671	0.085	0.263	5	358.115
$\phi_{SVL} P.$	svl	constant	constant	370.834	0.000	0.306	1.000	3	364.767
$\phi, P.$	none	constant	constant	370.950	0.116	0.289	0.944	2	366.916
$\phi_{mass} P.$	mass	constant	constant	371.592	0.758	0.209	0.684	3	365.525
$\phi_{SVL*SVL^2} P.$	svl and svl ²	constant	constant	372.718	1.884	0.119	0.390	4	364.605
$\phi_{mass*mass^2} P.$	mass and mass ²	constant	constant	373.587	2.753	0.077	0.253	4	365.474

No model was significantly more parsimonious than the null model, indicating the lack of an effect of size at the time of release.

Table 9. Model comparisons for the effect of initial capture site on survival rate estimation (ϕ).

Model Notation	Survival Rate Estimation		Recapture Probability Estimation	Model Parsimony					
	Grouping	Time	Time	QAICc	Delta QAICc	QAICc Weights	Model Likelihood	Number of Parameters	QDeviance
ϕ, P_T	one	constant	varied	242.500	0.000	0.993	1.000	3	11.724
$\phi_{\text{trap site}}, P_T$	trap site	constant	varied	252.466	9.966	0.007	0.007	8	11.348
$\phi, P.$	one	constant	constant	245.313	0.000	0.993	1.000	2	16.571
$\phi_{\text{trap site}}, P.$	trap site	constant	constant	255.216	9.903	0.007	0.007	7	16.190

No effect of the initial trap area within the donor site was found.

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Nicholas Osman was born and raised in Tampa, FL. In 2005 he received a Bachelor of Science degree in Environmental Science at the University of Florida, during which time he completed a summer internship at Canaveral National Seashore monitoring sea turtle nesting. After a year of environmental consulting and post-bachelor's courses, he began work toward his Master of Science degree in Biology at the University of South Florida in 2006. Nicholas was named a National Wildlife Refuge System Centennial Scholar in 2007 by the National Fish and Wildlife Foundation. He has presented his research nationally at the 2008 and 2009 Joint Meetings of Ichthyologists and Herpetologists and completed his degree during the summer of 2010. He hopes to pursue a career that will allow him to marry his love of nature, his passion for teaching, and his understanding of ecosystems and organisms.